Detailed appraisal of the offshore wind industry in China

Working with:

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中节能风力发电股份有限公司
CECEP Wind-Power Corporation

中国风能协会
CWEA

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Chinese Wind Energy Association (CWEA) was founded in 1981 as a non-profit social entity, registered with the Ministry of Civil Affairs of the People's Republic of China. CWEA aims to promote the advancement of China's wind energy technologies, drive the development of China's wind energy industry and enhance the public awareness of new energy. It helps promote international academic and technical cooperation; provide a bridge between the government and institutions; establish good relationships with domestic and overseas wind societies and cooperate with them; communicate with scientists and engineers closely.

CECEP Wind-Power Corporation develops and operates wind energy projects. The company was formerly known as China Energy Conservation Windpower Investment Company Limited. CECEP Wind-Power Corporation is based in Beijing, China. The company operates as a subsidiary of China Energy Conservation and Environmental Protection Group.

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Executive Summary

China's energy demand continues to grow rapidly, most of it met by coal (70%) and oil (19%). Electricity supply is dominated by coal, though hydro already makes an important contribution. However, the government has committed to reduce energy intensity and increase use of renewables. To date, China has focussed on driving the development of onshore wind as a key contributor to its renewables targets, with total capacity at 75GW, a CAGR growth of 69% from 2001 to 2012. However, the challenge of connecting a lot of this capacity to the energy hungry eastern coastal regions as well as a desire to diversify energy sources has led to an increasing focus on offshore wind as a potential new source of renewable energy close to the demand. Indeed, the government has set ambitious targets of 5GW of installed offshore wind capacity by 2015 and 30GW by 2020 that would eclipse capacity in other countries. However, China faces numerous challenges to the development of the offshore wind industry, highlighted below.

Policy

While targets provide a market signal of the seriousness the government takes, it has not been met with clear guidance on the feed in tariff rates that have been set too low and do not offer a definitive timeframe for developers to be able to make effective investment decisions. Given the relative immaturity of the offshore industry in China and the lack of commercial projects, it is not surprising that the government itself needs more clarity about the likely costs of project development to enable the appropriate tariff to be set. A reliable study around the future costs of deployment would help both government and developers.

Cost

The proximity to shore of China's farms (typically less than 15km) makes them similar to Round 1 and Round 2 sites in the UK, where typical capex ranged from around £1.2m/MW to £1.5m/MW (BWEA and Garrad Hassan, 2009a). Analysis we have reviewed indicates that the deployment costs in China are similar, at around £1.3m/MW to £1.4m/MW. While in the UK over the last five years costs have escalated dramatically due to the more challenging conditions of farms further from shore and in more difficult met-ocean conditions, where capex has doubled to £3.0m/MW. So any assessment of future costs in China must account for changes in location so farms.

Consenting & Connections

The process of granting consents to developers can take two years. In an effort to speed up approvals, the National Energy Administration (NEA) has delegated authority to the regional government; however, local authorities often lack the skills to effectively evaluate proposals, thus shifting the approval process back to central government.

As most of the farms are off the eastern coast where grid infrastructure is robust, there is little issue here. However, connecting farms to shore via cables is a challenge given that grid companies have limited capabilities and experience in this area, which will become more acute as farms move further from shore.

Technology

China faces a number of challenges around the technical deployment of offshore wind farms:

- Turbines: European offshore wind turbines are moving to beyond 95% availability, a key factor for achieving satisfactory project returns. Reliability of Chinese turbines is thought to be less than this, with a key issue being the gearbox. Some OEMs are moving to gearless turbines but these also have challenges around weight and hence additional cost of fabrication and installation. Corrosion and heat Is also a major challenge given the unique conditions off the China coast.

> Foundations: The sea bed off China's east coast (within 5-30m depth) is characteristic of soft, silty soils which are unlike soil conditions in Europe. This causes difficulty with regard to foundation type and installation techniques. Selecting appropriate foundations will therefore be crucial, and while there may be available solutions from existing European technologies, there is likely to be scope for local R&D to develop bespoke solutions for China, such as suction buckets.

> Installation: The lack of expertise as well as bespoke vessels makes installation the key cost in Chinese offshore wind development. Additionally, China lacks skills in hammering techniques as well as offshore assembly.

> Operations & Maintenance: Poor turbine reliability significantly adds cost to O&M and so can greatly reduce developer margins over time. A lack of expertise around transfer vessels also limits the operation window for conducting repairs.

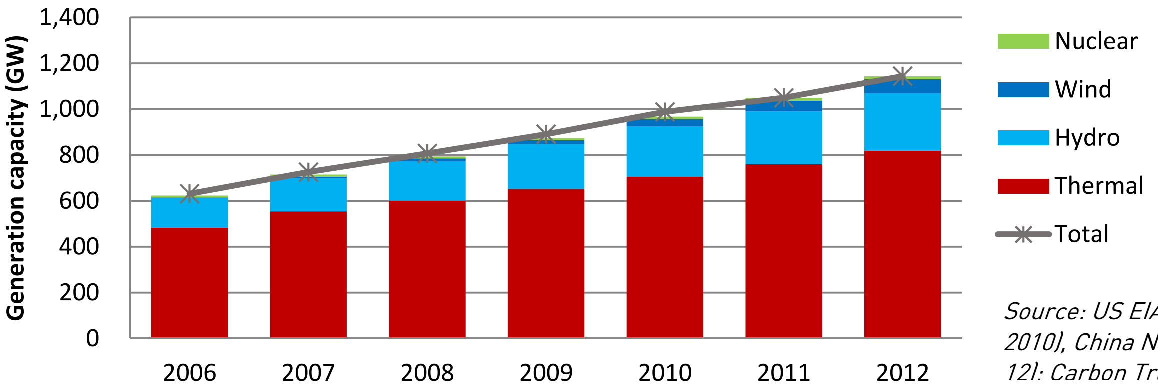
Above all, China has leveraged its skills and capabilities from the onshore wind industry to the offshore wind market where the technical challenges are much greater and where the weather conditions more impactful on turbine performance. Furthermore, initial demonstrations in China have focussed on the inter-tidal range; given that the NEA has insisted that future farms be at least 10km from shore, a rapid learning is now taking place that will take time to flow through to improved capabilities, technology and equipment. But given the rapid growth of the onshore market, there can be confidence that China can achieve its offshore wind targets, perhaps not by 2015, but perhaps by 2020.

Market

1.1 China Economy and Energy Needs

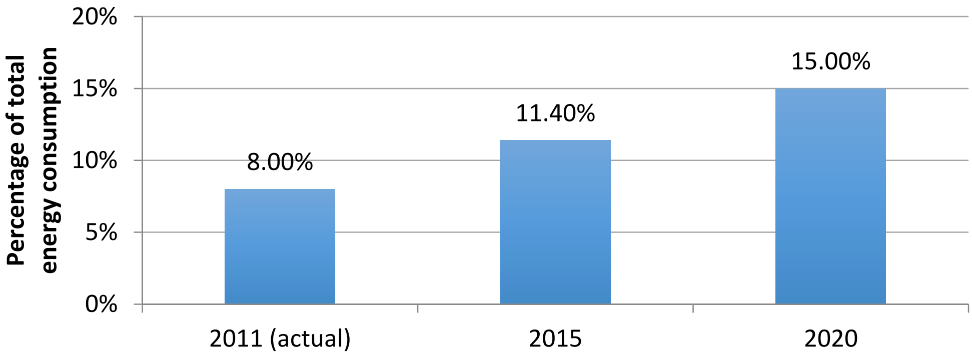
China is the world's second largest economy, and recent economic growth has been accompanied by increased energy consumption, with China now the largest consumer of energy and the largest emitter of carbon dioxide. Indeed, electricity demand growth has exceeded economic growth in recent years (Innovation Norway, 2013). Electricity demand in China has increased dramatically over the past decade, with total electricity consumption in 2012 at a staggering 4,693 TWh (generating capacity = 1,144 GW), representing a three-fold increase since 2002 (IndexMundi, 2013). The majority of this electricity is supplied by coal-fired power stations, with hydro power also increasing its share of the energy mix in recent years (Fig.1.1.1). However, with electricity demand expected to reach 8,000 TWh by 2020 and 10,000 TWh by 2030 (IEA, 2011) and increasing pressure to develop cleaner sources of energy, in 2006 the Chinese government set ambitious targets for renewable energy through its Renewable Energy Law (REL), which requires that 15% of primary energy comes from renewables by 2020 (NEA, 2013) (Fig.1.1.2). This desire for a more sustainable energy supply strategy is explicitly outlined in China's 12th Five-Year Plan (2011-2015), which states that China "will promote diversified clean energy sources and other measures to encourage changes in energy production and use."

Fig.1.1.1. Electricity installed capacity in China



Source: US EIA (2006-2010), China NEA (2011-12); Carbon Trust analysis.

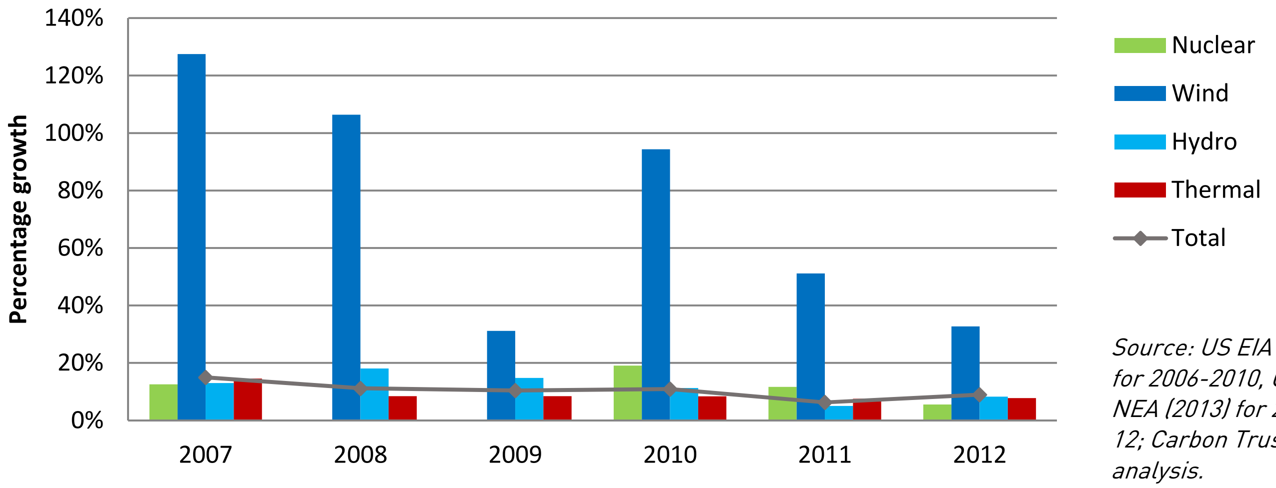
Fig.1.1.2. China targets for non-fossil energy consumption as percentage of total primary energy consumption



Source: China NEA (2011).

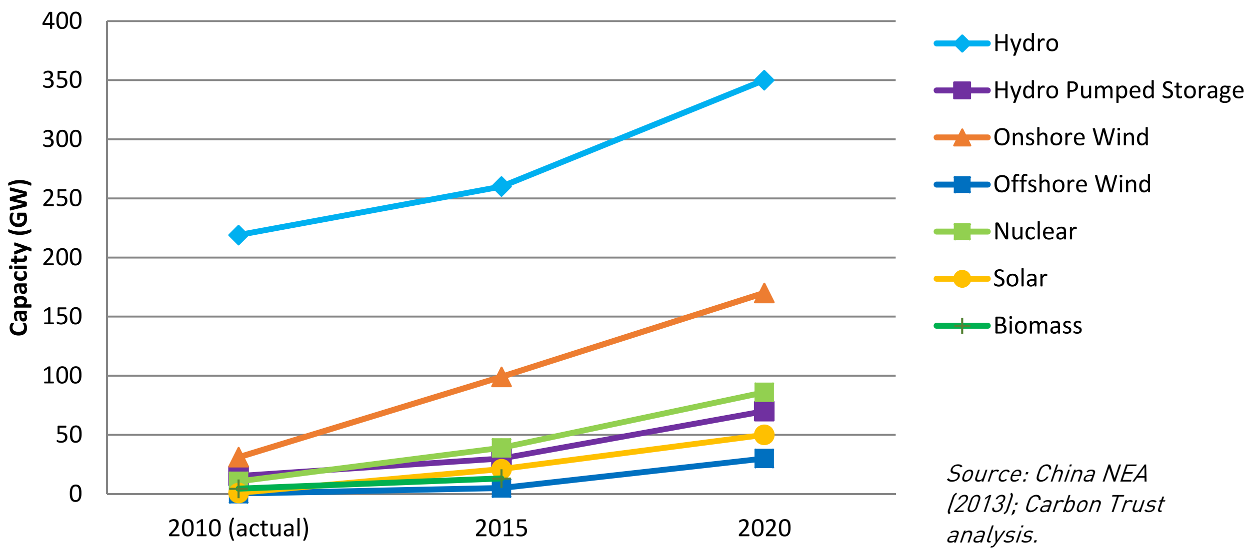
Wind energy has emerged as a key pillar of China's renewable strategy, with its installed capacity growth rates exceeding those of any other energy source in recent years (Fig.1.1.3), and propelling China to become the largest installer of wind energy in the world. This growth has been almost entirely focussed on onshore wind, with Chinese manufacturers emerging as key players in the onshore wind industry. However, issues surrounding transmission costs and losses has left many onshore wind farms idle and disconnected from the grid, slowing the growth of China's onshore industry dramatically. With central government still committed to maintaining wind energy as a key component of its renewable energy mix (Fig.1.1.4), China is beginning to switch greater focus to offshore wind power. Indeed, China's offshore wind resource has been estimated at 200 GW in water depth 5-25m and 500 GW in water depth 5-50m (GWEC, 2012).

Fig.1.1.3. Percentage growth in electricity installed capacity in China (2007-2012)



Source: US EIA (2010) for 2006-2010, China NEA (2013) for 2011-12; Carbon Trust analysis.

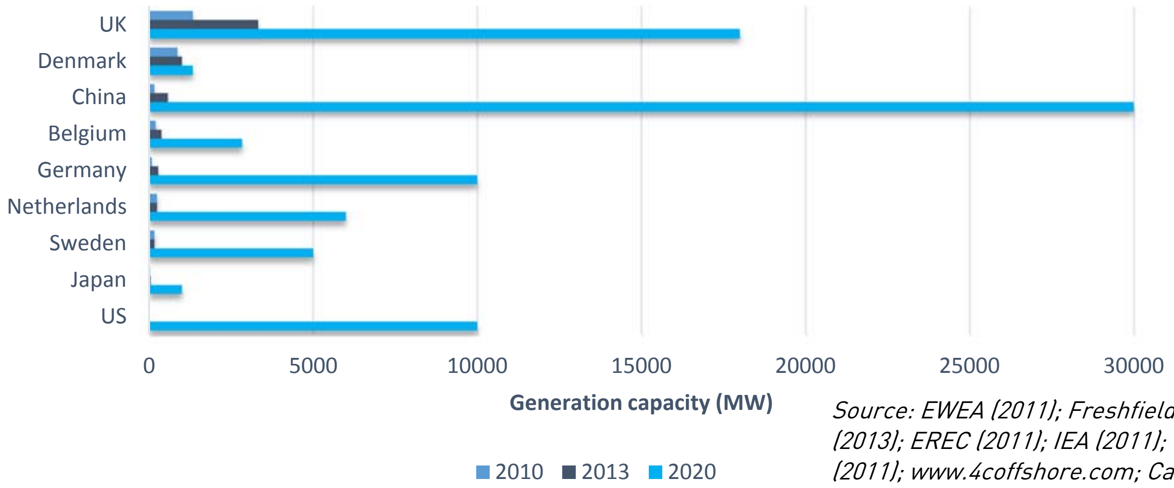
Fig.1.1.4. China's 12th Five-Year Plan for Renewable Energy



Source: China NEA (2013); Carbon Trust analysis.

The Chinese government has set ambitious targets to scale-up the deployment of offshore wind power. China's 12th Five Year Plan for Energy set a goal of 5 GW capacity by 2015 – a ten-fold increase from current installed capacity of 565 MW – and 30 GW by 2020 (fig.1.1.5). This would require a build-out rate of 5 GW per year on average beyond 2015 (equivalent to current global capacity) – a level of growth which is unprecedented in the offshore industry and would see China overtake the UK as the market leader in offshore wind energy sometime between 2015 and 2020. Importantly, China's wind goals (onshore and offshore) also have targets that set the amount of energy produced (190 TWh per year), so that a focus is put on efficient and effective energy generation, rather than simply building capacity (Innovation Norway, 2013).

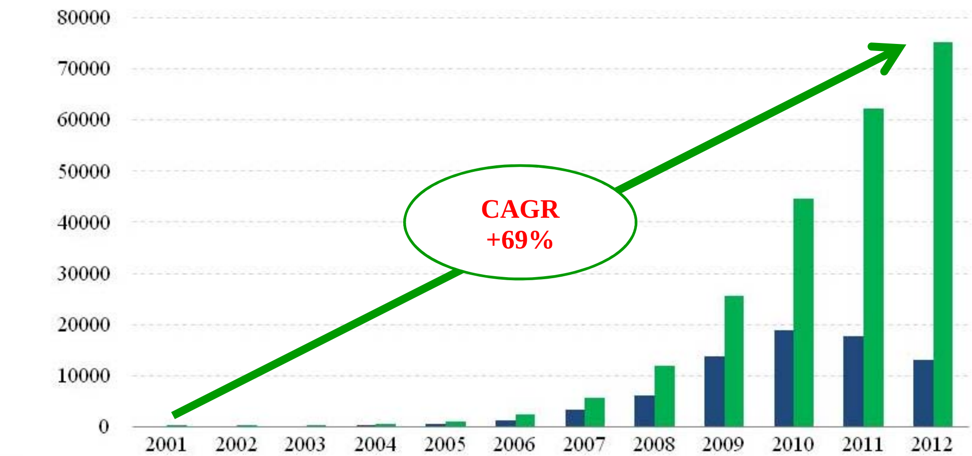
Fig. 1.1.5. National offshore wind capacity targets to 2020



Source: EWEA (2011); Freshfields Bruckhaus Deringer (2013); EREC (2011); IEA (2011); U.S. Dept of Energy (2011); www.4coffshore.com; Carbon Trust analysis.

A comparison with the growth of China's onshore wind industry indicates that reaching these targets for offshore wind could be feasible (Fig.1.1.6). Indeed, there may be opportunities to transfer manufacturing and technology capabilities between the two industries, particularly between turbine manufacturers. Nevertheless, it is widely accepted that offshore wind carries many more challenges than the onshore industry and, as such, the rate of deployment should be expected to be slower.

Fig. 1.1.6. China installed capacity of onshore wind power



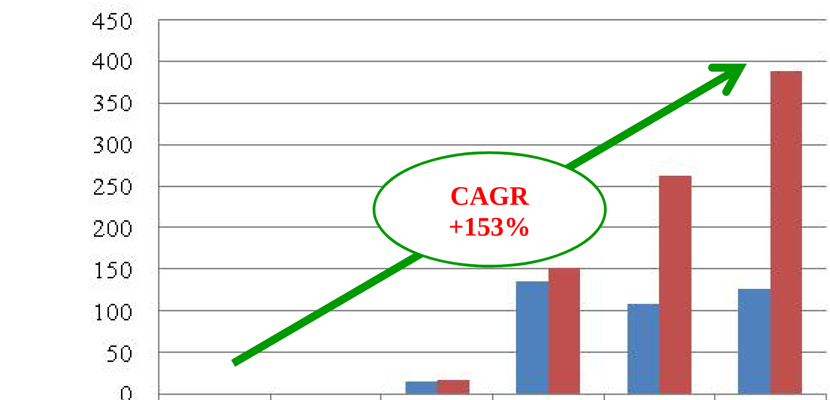
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Annual/MW	42	66	98	197	507	1288	3311	6154	13803	18928	17631	12960
Total/MW	381	448	546	743	1250	2537	5848	12002	25805	44733	62364	75324

Source: CWEA (2013).

China's offshore wind industry has already shown encouraging signs of growth (Fig.1.1.7); however, a ten-fold increase from 565 MW in mid-2013 (389 MW by end of 2012) to 5 GW by 2015 will require a significant scaling up of deployment. Adding 4.5 GW of capacity in ~18 months, to reach 5 GW, would surpass what the onshore wind industry took 3-4 years to achieve, between 2003 and 2007, when the industry was at a similar stage of maturity. There are a significant number of projects in the pipeline, with sufficient capacity consented to reach the 2015 target (Fig.1.1.8); however, disputes over the level of feed-in-tariff and poor coordination between state organisations has stalled construction on a number of sites, making it unlikely that the 5GW target will be reached by 2015. Recent industry estimates consider 2.5-3 GW by 2015 to be a more realistic target (Wind Power Monthly, 2013).

However, if offshore wind can parallel the longer term growth rates realised in the onshore industry, the 2020 target of 30 GW installed capacity might be achievable. The onshore industry also initially struggled for a 2-3 year period until suitable tariffs and policies were implemented, and the offshore industry can expect to mirror a similar level of growth as the industry reaches critical mass and economies of scale bring returns to developers and investors (Quartz & Co., 2013). Furthermore, the government has recently identified offshore wind as a priority industry, with a view to encouraging offshore wind development through favourable policies and incentive mechanisms, which should add to the growing optimism of reaching its near- and medium-term targets.

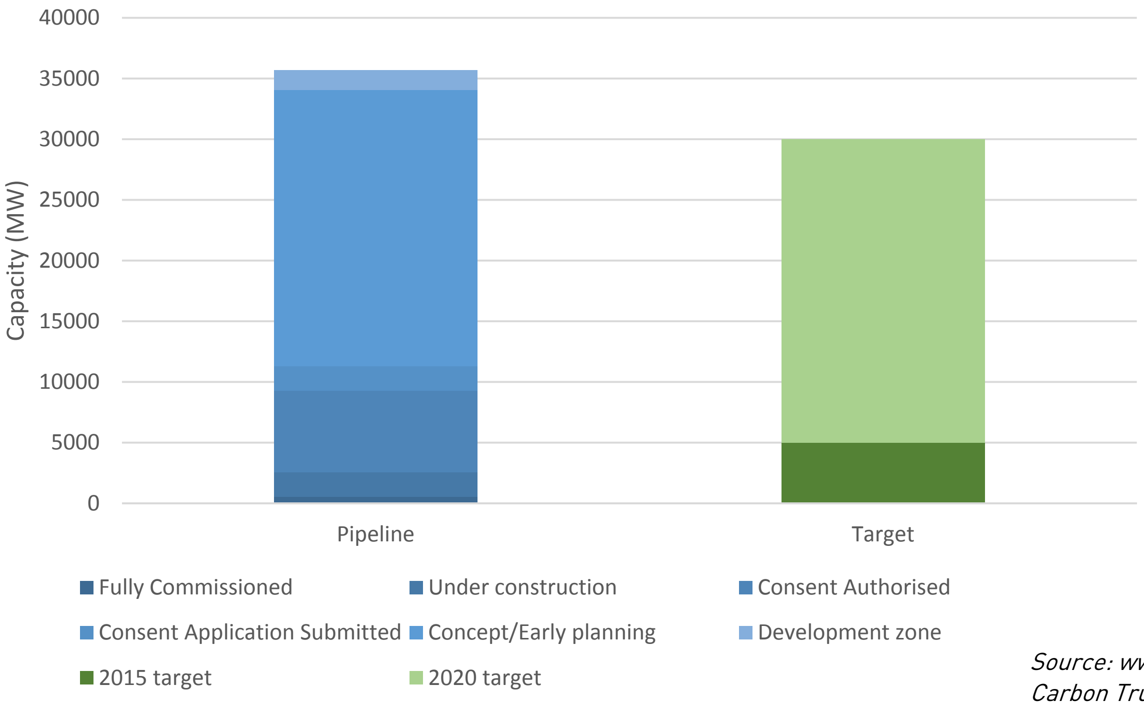
Fig. 1.1.7. China offshore wind capacity, installed 2007-2012



	2007	2008	2009	2010	2011	2012
Annual/MW	1.5	0	16.0	135.5	109.6	127.0
Total/MW	1.5	1.5	17.5	153.0	262.6	389.6

Source: CWEA (2013).

Fig.1.1.8. Pipeline of offshore wind projects versus national targets



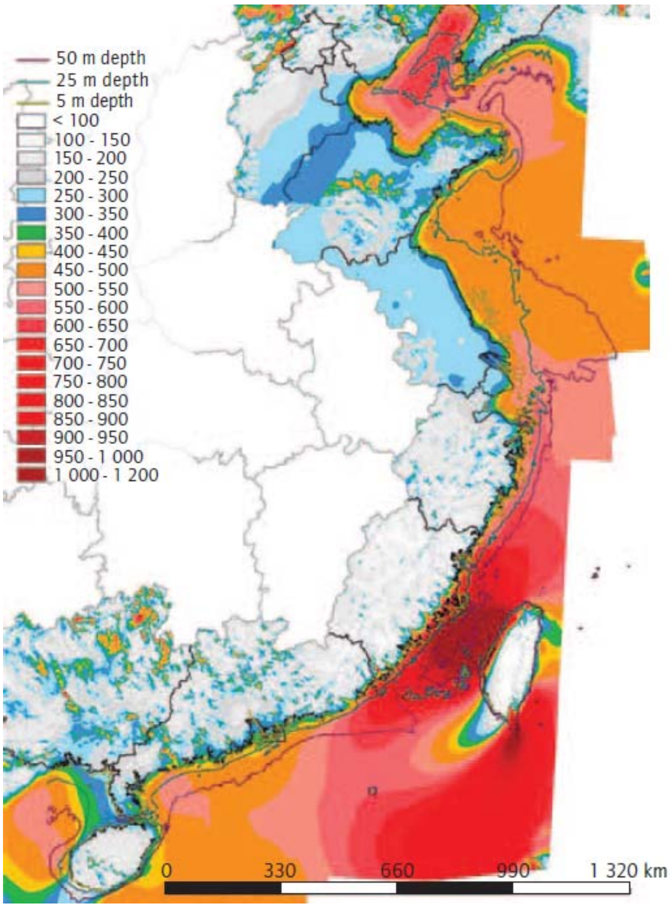
Source: www.4coffshore.com; Carbon Trust analysis.

1.2 Offshore Wind Resource

The offshore wind potential off China's east coast has been estimated at 200 GW within water depth <25m, with an additional 300 GW available in water depths between 25m and 50m (CWEA, 2013), and all within areas that do not interfere with shipping routes, fishing use, and areas where typhoons of Force 3 or stronger occur (IEA, 2011) (Fig.1.2.1). Wind speed increases from north to south along China's east coast, partly due to the more frequent occurrence of typhoons in the south. Typhoons are a potential cause of difficulties for offshore wind development; however, analysis by the Chinese Meteorological Association has discovered that only a few isolated areas off the east coast of Fujian and Hainan Island experience wind speeds >70 m/s (the upper threshold for Class I turbines) (World Bank, 2008).

The frequency of summer typhoons in the south means that the most abundant wind resource (Force 6 and above) is located in the Taiwan Strait. Offshore areas near Fujian, southern Zhejiang, and Guangdong are therefore prime locations to maximise this wind resource. The occurrence of typhoons north of the Yangtze River is very limited, but the wind resource is still sufficient for significant offshore development, particularly in northern Zhejiang and Jiangsu. Jiangsu alone has an estimated potential near-offshore capacity of 14 GW and at depths of 5 to 25m (IEA, 2011). Average wind speeds in Fujian are ~10m/s, while other provinces typical experience average wind speeds of 6-8m/s, which are still sufficient to harness optimum levels of power output (Quartz & Co., 2013).

Fig.1.2.1. Distribution of annual average wind power densities in 5-50m depth sea areas



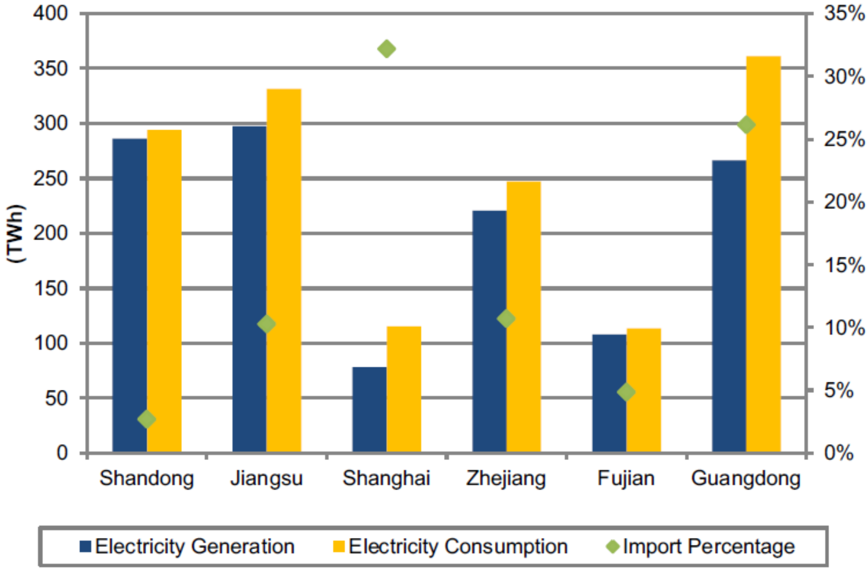
Source: IEA (2011)

Despite these macro-level wind resource assessments, there is a lack of accurate wind resource data at site scale. The importance of wind speed cannot be overemphasised, as it is critical in determining the commercial viability of wind power projects. Accurate wind resource measurement to ascertain the power output of a site is therefore crucial before making expensive offshore investments.

1.3 Energy Supply and Demand

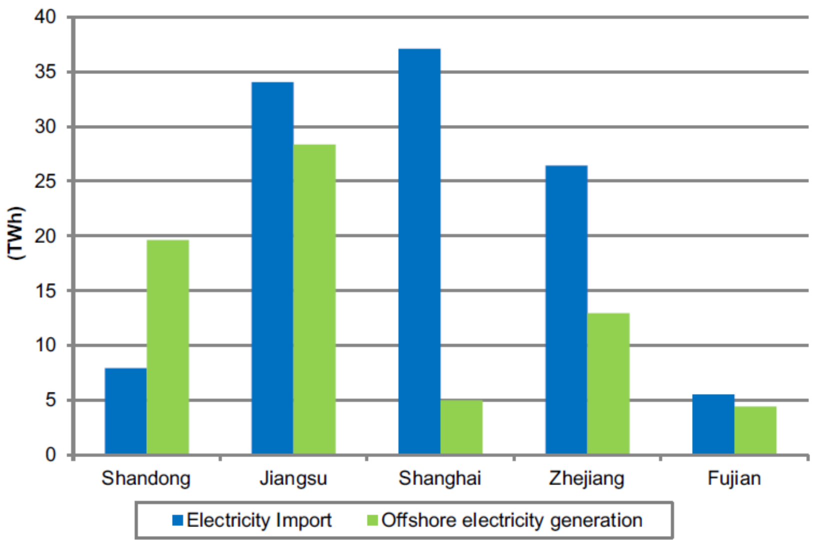
China's electricity demand is concentrated along its east coastline. Offshore wind represents an attractive energy solution here as they lack coal resources and are becoming increasingly dependent on transporting fuels from inland China or importing from abroad (fig.1.3.1). These provinces also suffer from power shortages in the summer months, with power generation and grid transmission systems unable to cope with rising demands. Considering the richness of offshore wind resources and its proximity to markets, developing offshore wind energy in coastal regions could be an effective solution to solve their power shortage, relieve the stresses both from railway and power transmission systems, and reduce greenhouse gas emissions (Hong & Moller, 2012). Fig.1.3.2 shows the extent to which offshore wind off five of China's coastal provinces could fill their respective electricity gaps in 2020, which cumulatively would represent 63.3% of the total imported electricity in these provinces.

Fig.1.3.1. Electricity generation and consumption in China's coastal provinces in 2009



Source: Hong & Moller (2012).

Fig.1.3.2. Imported electricity in 2009 compared to offshore wind generation in 2009.



Source: Hong & Moller (2012).

There is also significant appeal over onshore wind power, where the wind resource is concentrated in the northern and western regions of China (Fig.1.3.3). China's onshore industry has suffered from significant transmission costs and energy losses, which resulted in many sites being left without connection to the grid (Yu & Zheng, 2011). With China's extensive wind resource being located so close to China's populous urban hubs, it is expected that the current grid infrastructure would require only limited modifications to connect farms to the grid.

Fig.1.3.3. China's onshore wind generation vs. provincial electricity demand

Source: Ma & Weekes (2010).

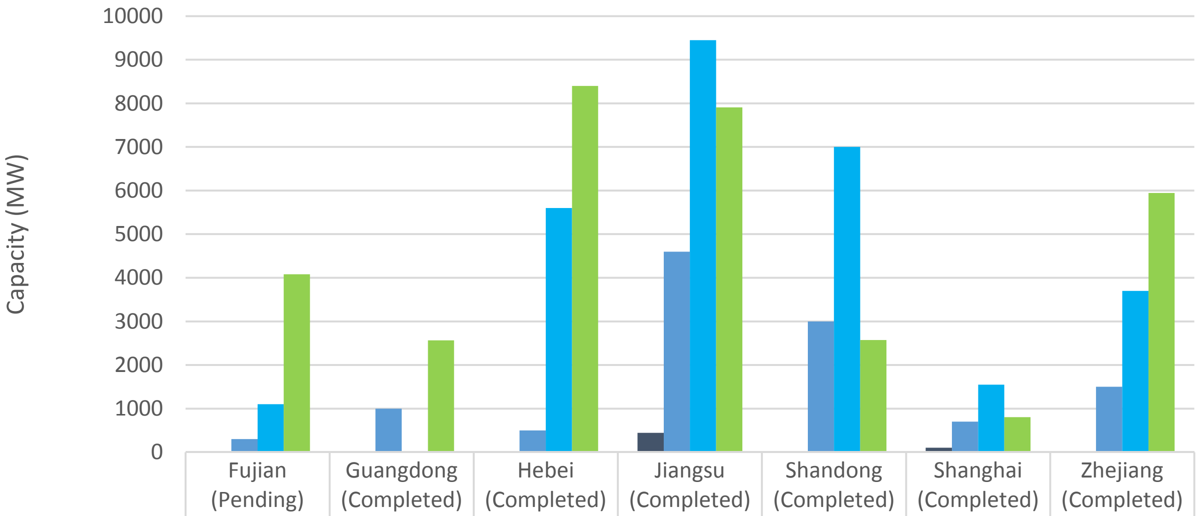
While China has an abundant offshore wind resource, the strongest winds appear to be onshore, in the inland northern regions (World Bank, 2008). The issues facing China's wind industry therefore differ from the situation in Europe, where the increased resource offshore goes some way to counterbalancing the increased capital costs. Rather, in China, it is the proximity to demand and reduced transmission costs that provide the incentive for offshore wind development.

1.4 Provincial Distribution of Offshore Wind

In April 2009, the National Energy Administration (NEA) required each coastal province to formulate a provincial offshore wind development plan, including the number of farms, their size, and their location. Offshore wind plans have been completed in six provinces to date, with Jiangsu showing the greatest level of ambition (fig.1.4.1). Jiangsu already leads China's offshore wind market with 79% of installed capacity, most of which is situated in intertidal zones, and has submitted a plan for 4.6 GW installed capacity by 2015 and 9.45 GW by 2020. Shanghai, which includes the first and largest commercial offshore wind farm in China – the 102MW Donghai Bridge project – has more modest targets and has already had its provincial plan approved by the NEA, including an additional 600 MW by 2015 and total installed capacity of 1.55 GW by 2020. Meanwhile, despite very little installed capacity so far, Shandong and Hebei have ambitious plans to scale-up offshore wind by 2020; and Guangdong has completed a provincial plan which includes a target of 10.7 GW by 2030 (Innovation Norway, 2013).

There are already a significant number of projects in the pipeline to deliver the target capacity, in some cases far outstripping 2020 targets (e.g. Fujian, Hebei, and Zhejiang), and in others appearing to fall short of the plans (e.g. Shandong and Shanghai). However, it should be acknowledged that much of this pipeline is at the concept stage and subject to change significantly over the coming years. Nevertheless, such ambition affirms that, despite delays, the industry remains confident about the potential for growth and development in China.

Fig.1.4.1. Provincial plans for offshore wind energy in China versus project pipeline.

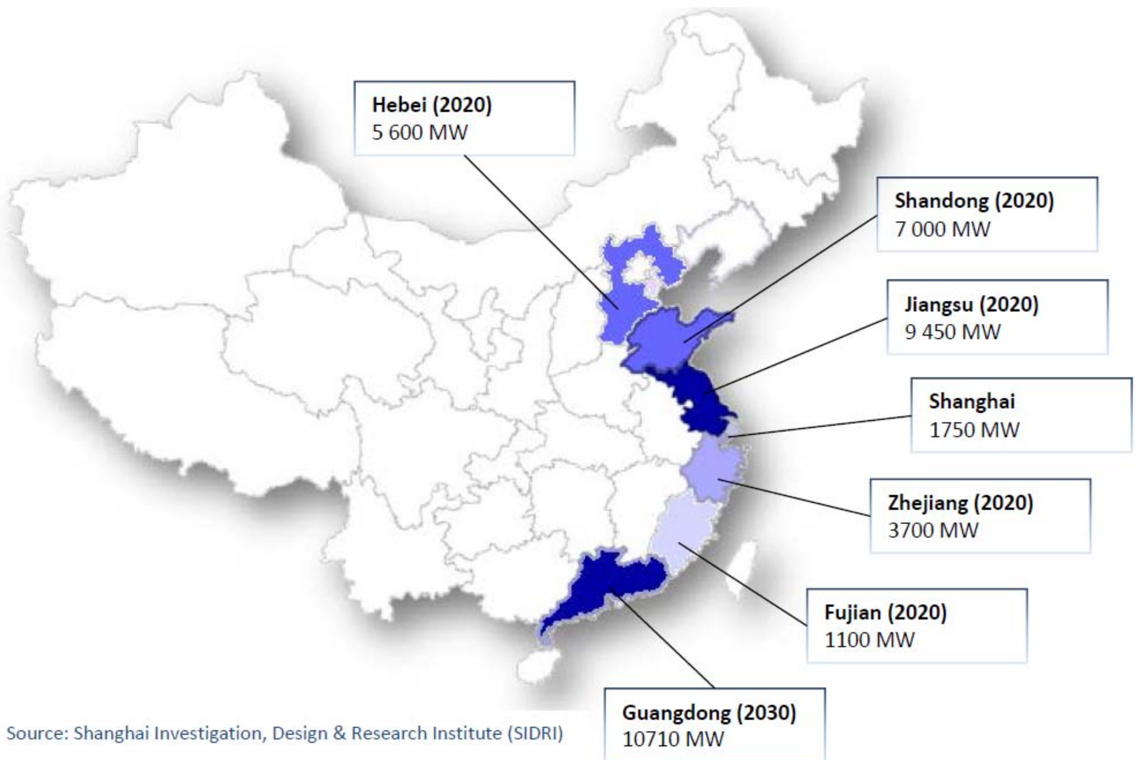


	Fujian (Pending)	Guangdong (Completed)	Hebei (Completed)	Jiangsu (Completed)	Shandong (Completed)	Shanghai (Completed)	Zhejiang (Completed)
2013 (current)	5	0	0	444	12	102	0
2015	300	1000	500	4600	3000	700	1500
2020	1100		5600	9450	7000	1550	3700
Pipeline	4080	2566	8398	7907	2572	804	5946

*Guangdong has set a target of 10.7 GW by 2030

Source: Hong & Moller (2012); Innovation Norway (2013); Quartz & Co (2013); www.4coffshore.com; Carbon Trust analysis.

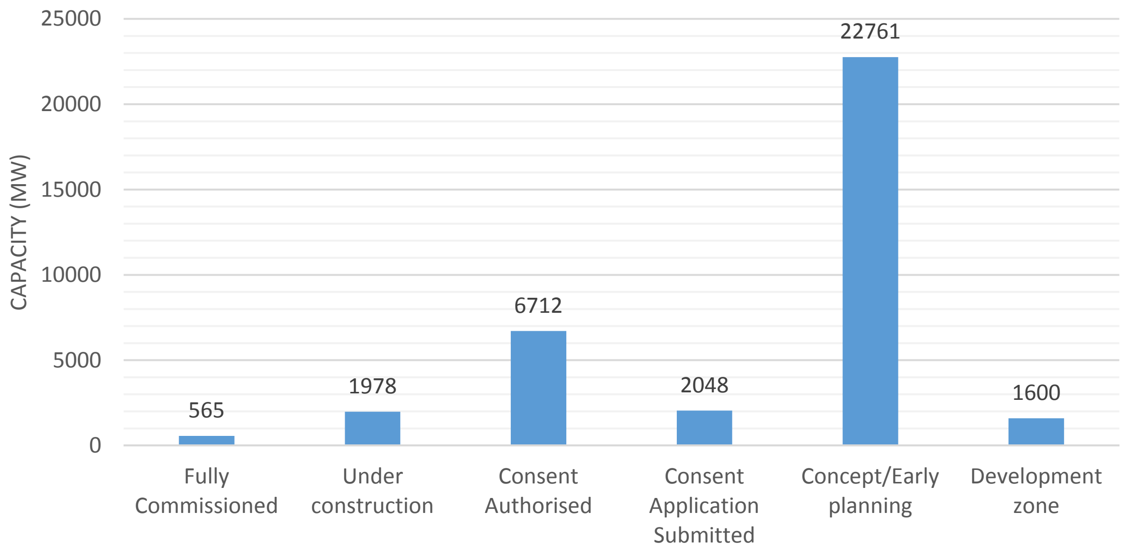
Fig.1.4.2. Provincial plans for offshore wind energy in China



Source: Innovation Norway (2013). (N.B. Guangdong target is for 2030).

The cumulative plans of all of China's provinces exceed the national targets (2015 = 11.6 GW planned vs. 5 GW national target; 2020 = 39 GW planned vs. 30 GW national target). However, as discussed in section 1.1, given the challenges the industry is facing (both regulatory and technical), the 2015 target in particular will be difficult to attain. Nevertheless, with 565 MW already installed, 1,978 MW under construction, and 6,712 MW consented (fig.1.4.3), China's potential to meet its near-term target appears somewhat more promising, particularly given that the consented projects must begin construction within two years from concession, otherwise the site will be re-opened to tender. Given that the typical wind farm in China takes 1-2 years to construct (e.g. Donghai Bridge), China appears on track to install ~9 GW by 2017, with analysis from Quartz & Co predicting up to 4.5 GW being achievable by 2015 (Quartz & Co., 2013).

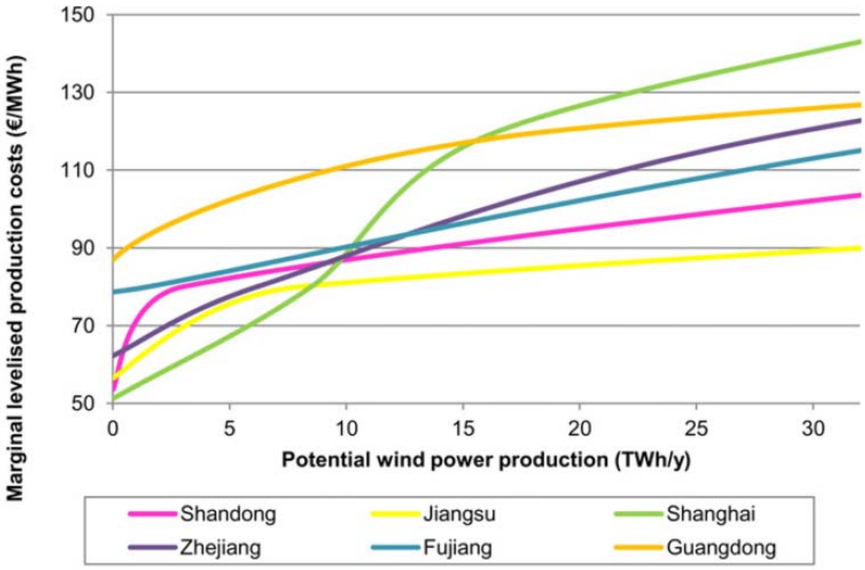
Fig.1.4.3. Status of China's offshore wind projects (installed and pipeline)



Source: www.4coffshore.com; Carbon Trust analysis

Unsurprisingly, these regional plans for installed offshore wind capacity are closely tied to the cost of offshore wind development. Analysis by Hong & Moller (2012), which calculated the cost of energy under tropical cyclone risk and spatial constraints, discovered that the lowest cost sites for offshore wind development are along the coasts of Jiangsu, Shanghai, Hebei, Liaoning, and Tianjin (fig.1.4.5). While Fujian is endowed with the highest wind density, its total technical potential of offshore wind energy is much lower than that of Zhejiang and Guangdong. Even though the largest technical potential of offshore wind energy is located in Guangdong, the spatial constraints exclude as high as 14.5% of its exploitable potential (Hong & Moller, 2012). Guangdong experiences 3-4 typhoons every year, and as such, development can only be planned in areas not susceptible to adverse weather conditions (Quartz & Co., 2013). In addition, the economic risk of tropical cyclones are fairly high in both Fujian and Guangdong, compared to other provinces such as Jiangsu and Shanghai which are at lower risk to tropical typhoons.

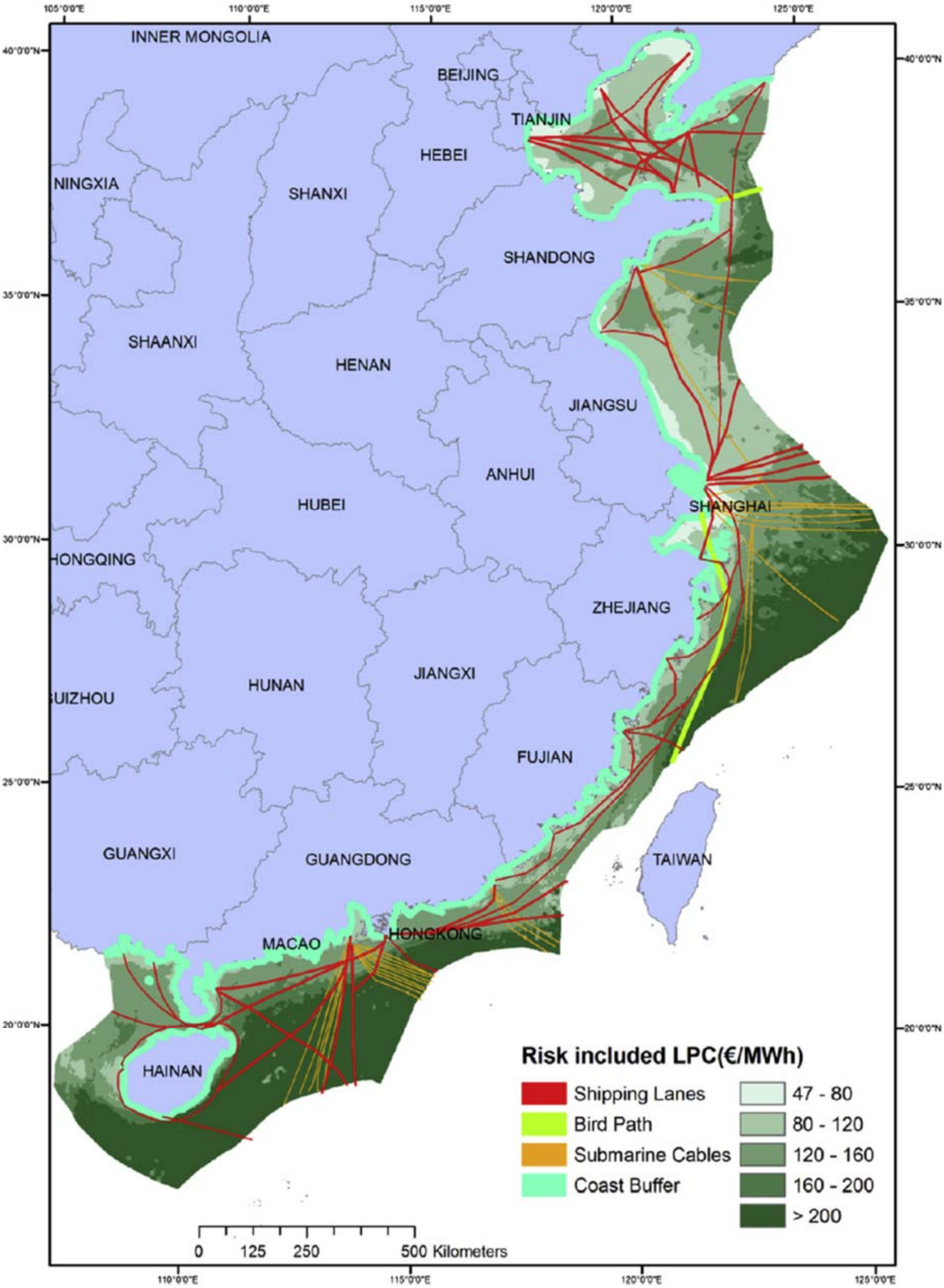
Fig.1.4.4. Marginal levelised electricity production costs in China's coastal provinces



Source: Hong & Moller (2012).

The relative costs of offshore wind development are also expected to vary over time, as capacity increases and spatial constraints in certain regions become more acute. Thus, while in the short term Shanghai is the most economically competitive location for developing offshore wind farms, costs are likely to increase dramatically as more cumulative electricity generation capacity is installed and sites must be developed further from shore (fig.1.4.4). In the long term, Jiangsu emerges as the most cost competitive province for the large-scale development of offshore wind farms, due to the level of wind resource around its extensive coastline, lack of spatial constraints from shipping routes and marine conservation zones, and lower risk from tropical cyclones.

Fig.1.4.5. Spatial distribution of levelised electricity production costs around China's coastal provinces



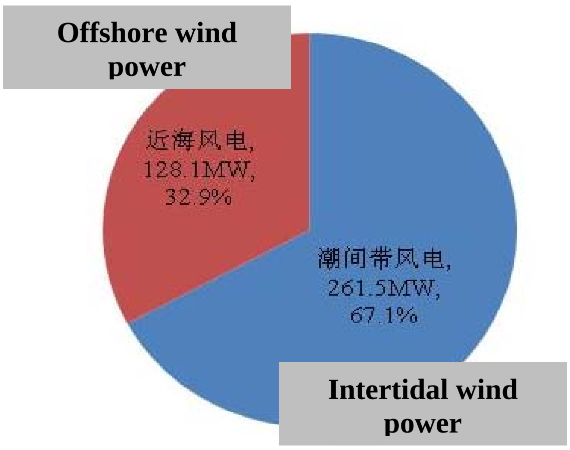
Source: Hong & Moller (2012).

1.5 Offshore Wind Sites

While China had installed 389.6 MW offshore wind power by the end of 2012, 67% of this was situated in intertidal zones, with just 128 MW located offshore (fig.1.5.1). Furthermore, the majority of this capacity (102 MW) is located in a single site – Donghai Bridge – with the remainder consisting of prototypes of various unit capacities for demonstration and testing purposes. The unique conditions of China's intertidal zone produced a number of challenges for offshore wind development, particularly with regard to installation and O&M, and very few solutions have been established. However, the intertidal projects to date have been valuable as a testing bed for different turbine and foundation designs. For example, the Rudong 182 MW intertidal wind farm in Jiangsu province tested 9 turbines from 8 manufacturers, as well as a variety of foundations, including monopiles and tri-piles, and introduced a number of players to the offshore industry (Innovation Norway, 2013).

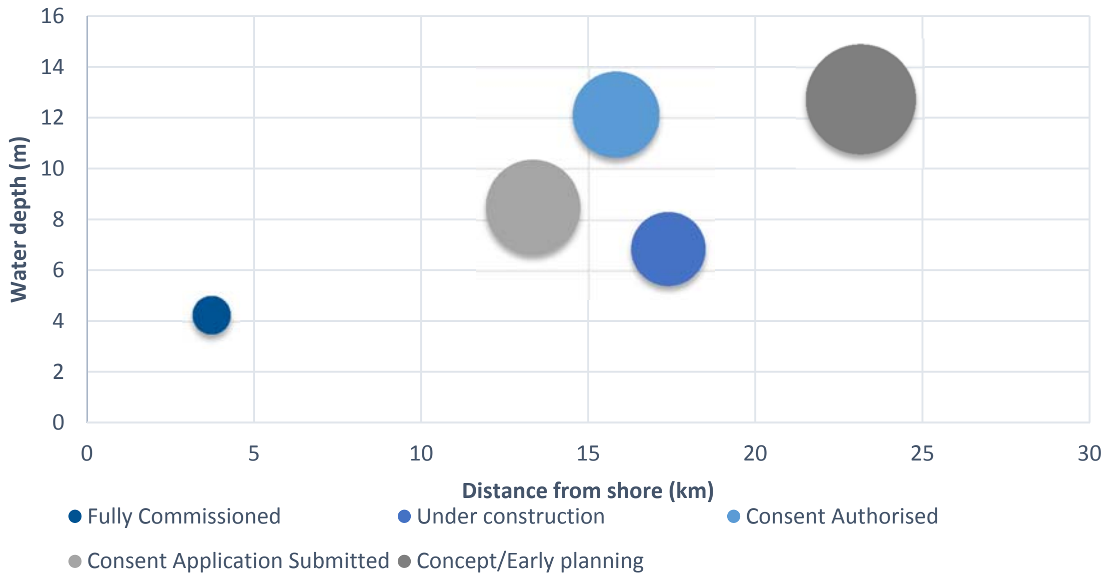
However, new regulations introduced in 2011 by the NEA and SOA through the "Implementation Rules of the Interim Measures for the Management of Development and Construction of Offshore Wind Power" dictate that, in principle, future offshore wind farms should be located no less than 10km from shore and in water depth no less than 10m if the width of the tidal flat is <10km (GWEC, 2012). The introduction of this restriction has forced developers to focus their attention towards building capacity in the development of offshore wind farms, typically in 10-15m ocean depths and 10-20km from shore. The impact of this regulation is evident in the contrasting site locations between projects currently installed and those at under construction or in early stages of development (fig.1.5.2). With most sites located within 20km from shore and at depths of <15m, China's offshore industry is likely to encounter similar technical challenges to UK Round 1 and 2 locations, rather than the current UK focus on Round 3 sites, which are located up to 200km from shore and at depths of up to 60m (Carbon Trust, 2013).

Fig.1.5.1. Installed capacity in intertidal and offshore areas in 2012



Source: CWEA (2013).

Fig.1.5.2. Geographical conditions of selected existing and planned offshore wind farms in China



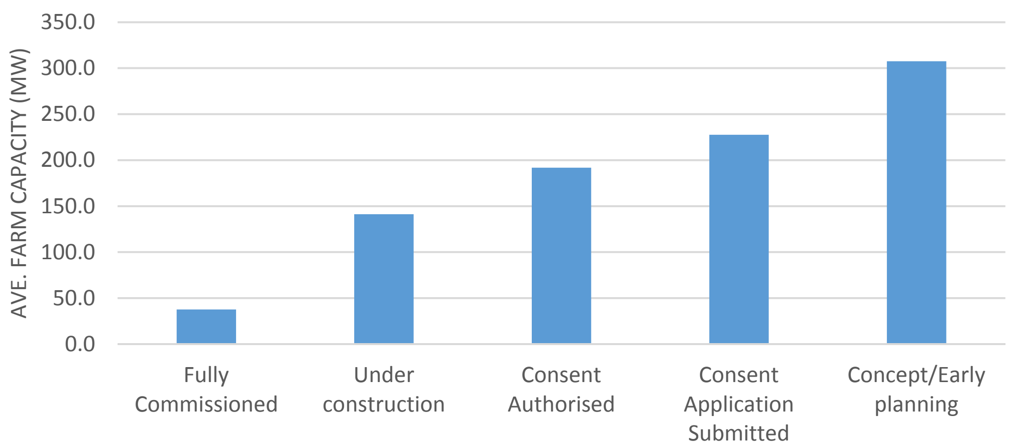
*Point size reflects average project capacity (see fig.1.5.3).

Source: 4coffshore; Carbon Trust analysis.

Thus while distance from shore and water depth are likely to be challenges, China may be able to benefit significantly from experience in the UK and elsewhere in Europe, where technological solutions exist and capability is strong. However, it is also expected that there will be some unique challenges for China's offshore industry.

Following the success of the Donghai Bridge project and various demonstration projects, the scale of future projects in the pipeline is expected to increase significantly, with more commercial-scale projects coming on-line (Fig.1.5.3). Whereas existing installed projects are small-scale demonstration/early-commercial sites, typically ranging from 2-100 MW capacity, there are plans to develop large arrays of up to 1.8 GW capacity by 2020. These sites are likely to deploy the 5+ MW turbines currently at the demonstration stage.

Fig.1.5.3 Average farm capacity of installed and planned offshore wind farms



Source: www.4coffshore.com; Carbon Trust analysis.

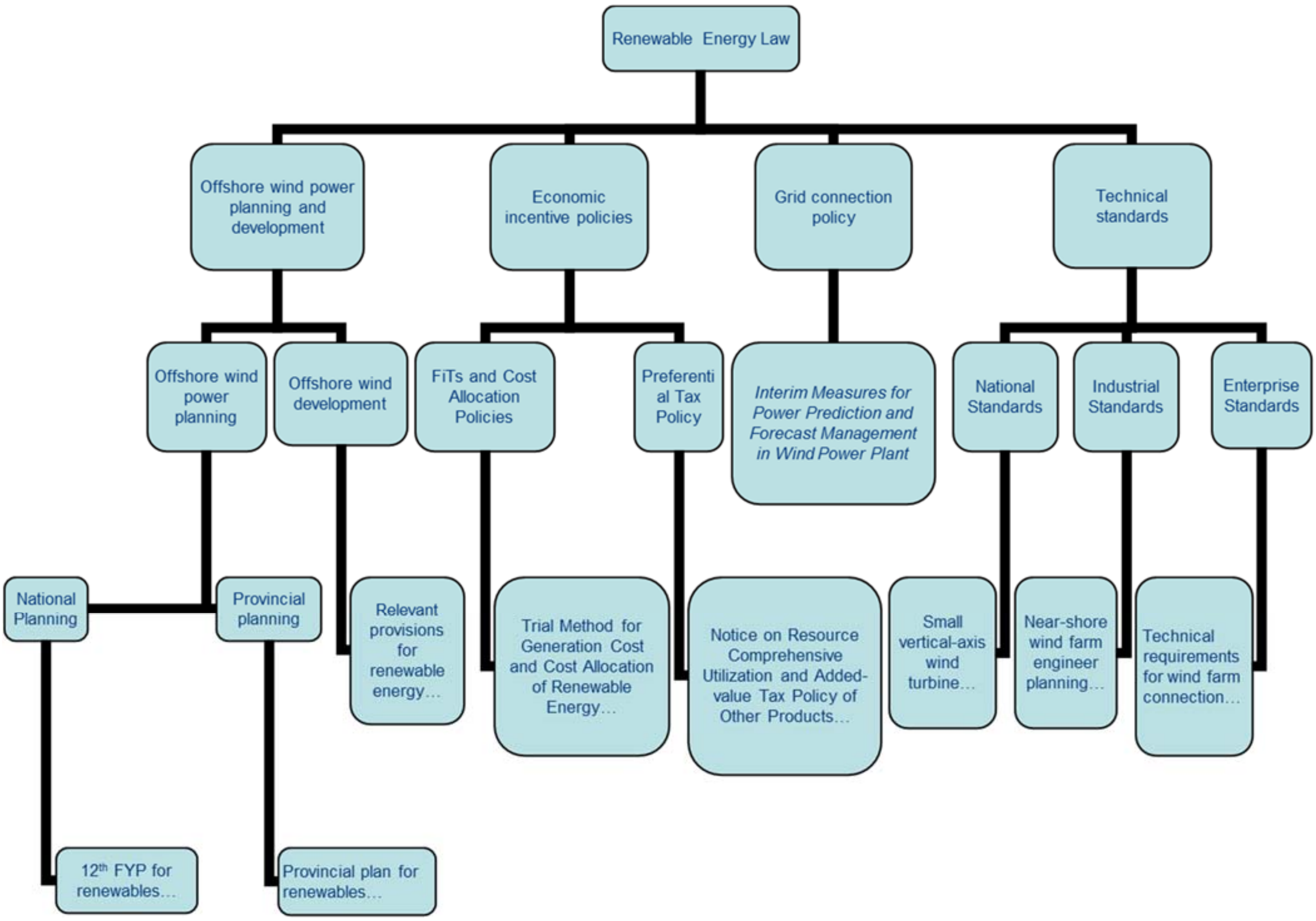
Policy & Regulatory Framework

Energy, and electricity in particular, is a highly policy dependent market, strongly shaped by regulation, incentives, and public goals. A prerequisite for a successful offshore wind market is therefore a good level of support from government. Such support is important for renewables as a whole but, given the relatively risky nature of offshore wind, it is particularly important in this area. Offshore wind development requires both significant capital and technical resources, and in order to mobilise these two key ingredients, investors must have confidence in the long term support of the sector by government. Without this, offshore wind will remain unnecessarily expensive or will not be developed at all (World Bank, 2008). According to analysis undertaken by the World Resources Institute, industry scale-up correlates with support policies with at least a three year time horizon, often with accompanying government commitment to the wind industry and ambitious targets for deployment (WRI, 2012). This has been evident in China's onshore industry, where steady growth was supported by a competitive feed-in-tariff, the availability of low interest rate project financing, research/industry clusters, and public awareness and support for wind power. However, this has yet to be paralleled in the offshore industry. Thus, while China has set clear and ambitious deployment goals for offshore wind, the lack of financial incentives has stalled the growth of the industry.

2.1 Renewable Energy Law

In order to promote the development of the offshore wind power industry, China has established a basic offshore wind power policy system. Based on the Renewable Energy Law (REL), the system consists of offshore wind power planning and development, economic incentive policies, grid connection policy, and technical standards (fig.2.1.1). The system is expected to evolve over time to provide comprehensive regulatory support for the industry.

Fig.2.1.1. Influence of China's Renewable Energy Law on offshore wind power.



Source: CWEA (2013)

Among the regulations included in the REL were a number of progressive policies to encourage investment in the industry. These included national targets, consenting policy, economic incentives, and grid connection policy.

National targets:

- **Deployment** – The government has set a target of 5 GW by 2015; 30 GW by 2030
- **Industry** – power companies with capacity greater than 5 GW must produce 3% of electricity from non-hydro renewables by 2010 and 8% by 2020 (Ma & Weekes, 2010). Since most power generators in China are large state-owned enterprises with a capacity of more than 5 GW, this impacts the quantity of electricity produced from renewables significantly.
- **R&D** – Targets have also been put in place to encourage increased innovative activity, including a target for R&D expenditure to account for 2.5% of GDP. During the 11th Five Year Plan period, an estimated 15.3% of government stimulus funding was directed towards innovation, energy conservation, ecological improvements and industrial restructuring; and in 2010 the government invested US$1.3 billion in clean energy R&D, including wind (WRI, 2012).

Consenting policy:

> **Planning** – the REL attempts to streamline planning on a nationwide basis to ensure more co-ordination between central and provincial governments. After problems in the first concession round, this now includes clear guidance on the roles of the respective government departments involved in offshore development.

Economic incentives:

> **Price** – the REL establishes a feed-in tariff for the price of electricity based on the region and type of energy. For onshore wind, the NDRC established 4 FITs in 2009 for 4 groups of regions (NDRC, 2009). Group I, with richest wind resource, is CNY 0.51 /kWh. Group II 0.54, Group III 0.58 and Group IV 0.61. However, crucially, fixed FITs for offshore wind are yet to be announced, with FITs for early offshore projects determined either by consenting or bidding (see section 2.2).

> **Renewable Energy Development Fund** – this compensates grid companies for the increased costs of purchasing power from renewable sources (Out-Law, 2013).

> **Preferential Tax Policy** - Investments in renewable energy benefit from favourable treatment both in terms of obligations for value added tax (VAT) and enterprise income tax (EIT). Since 2009, VAT for wind power has been reduced from 17% to 8.5% and income tax has been reduced from 33% to 15% (Xiliang et al., 2012).

Grid connection policy:

> **Connection** – Companies must connect wind farms to the grid, and grid operators have a legal requirement to source a proportion of their energy from renewable sources. Furthermore, developers are not allowed to begin construction until they have obtained grid connection approval.

> **Power Purchase Agreement** – Grid operators must purchase all renewable energy generated by licensed companies.

> **Power generation predictions** - In order to improve wind power connection, the REL requires all connected wind farms to set up a wind power predication and report system.

The REL did not move deployment forward significantly in itself, but by introducing medium and long-term renewable energy targets there was certainty in the market of the importance that the government was placing on offshore wind moving forward (WRI, 2012). However, the first round of concession tenders have experienced significant problems, namely through poor coordination between government departments and the absence of a sustainable and long-term feed-in-tariff.

2.2 First Concession Round

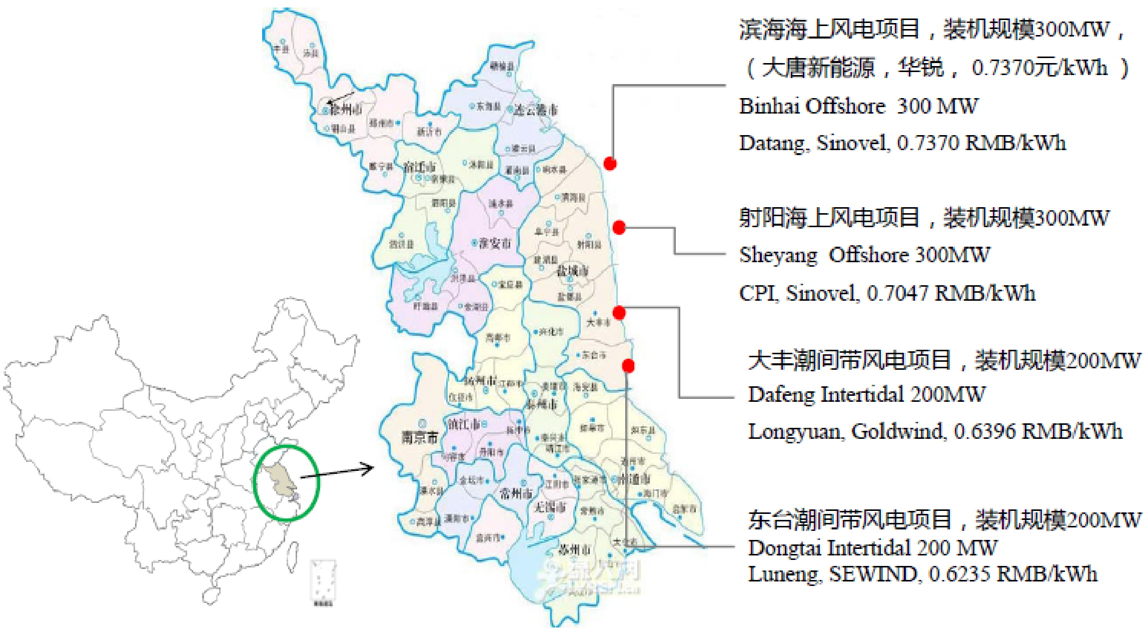
China's first round of concession bidding started in September 2010. Project developers were selected through an evaluation process that examines the bid's tariff, construction design, technological capacity, and performance record (Ma & Weekes, 2010); although low electricity price and high equipment localisation appear to be the prevailing factors in determining the winning bidder (Hong & Moller, 2012). Four projects totalling 1 GW power capacity were selected in four subsidiary counties of Yancheng city, Jiangsu; two of which were offshore and two of which were intertidal.

Table.2.2.1. First concession round project details

Project	Capacity (MW)	Developer	Feed-in-Tariff (CNY per KWh)	Construction started
Jiangsu Binhai Offshore Wind Farm	300	China Datang Corporation Renewable Power Company	0.7370	Sept 2013
Jiangsu Sheyang Offshore Wind Farm	300	China Power Investment Corporation	0.7047	Expected 2013
Jiangsu Dongtai Intertidal Wind Farm	200	Shandong Luneng Group	0.6235	Sept 2013
Jiangsu Dafeng Intertidal Wind Farm	200	China Longyuan Power Group	0.6396	Sept 2013

Source: CWEA; www.4coffshore.com.

Fig.2.2.1. Location of first round concession projects in Jiangsu province



Source: CWEA (2013).

2.3 Government Coordination

These projects were originally expected to complete within four years but construction only commenced in three of the projects in September 2013 (Binhai, Dongtai, and Dafeng), with construction expected to start in Sheyang in the final quarter of 2013 (4coffshore, 2013). This delay was in part caused by a lack of coordination and conflict between various government departments, particularly the National Energy Administration (NEA) and the State Oceanic Administration (SOA). While the SOA wants wind farms to be built as far as possible from the shore, in order to save space for fishing, transportation and many other uses, the NEA wants the opposite, in order to reduce the costs and technical challenges of installing wind farms further from shore. Indeed, while the NEA has a commitment to develop offshore wind farms in China, the SOA has no such mandate (Quartz & Co., 2013). Poor coordination led to certain areas being designated for both offshore wind development and other activities, with developers having to relocate to new sites, having incurred the costs for planning the original farm's development (EE News, 2012). For example:

- The Sheyang project, being developed by China Power Investment Corporation, was stuck in the project design phase due to the conflict of military use of the area (xinhuanet, 2013);
- The Dongtai project, being developed by Shandong Luneng Group, experienced a 10km relocation further offshore to make way for a wildlife conservation area, and only applied to the NEA for project approval in Nov 2012, a year and a half later than planned;
- The projects at Binhai and Dafeng, owned respectively by China Datang Corporation and China Longyuan Power Group, didn't apply to NEA for project approval until 2013.

In order to resolve this conflict, in 2010 the NEA and SOA jointly released a new set of regulations and frameworks for offshore wind projects, delegating responsibility for selecting developer bids and agreeing FIT rates to the NEA, and responsibility for site approval to the SOA. The regulations also specified that future concession projects should be located at least 10km from shore and 10m water depth if the tidal flat is more than 10km wide, and should avoid areas designated for commercial uses (e.g. fishing, tourism, military). This level of clarity over which offshore sites are licensed for development should ease the overall process and encourage developers to enter the market. The first four concession projects have since undergone a new round of environmental evaluation and cable routing (Innovation Norway, 2013), with construction having recently got underway in three sites (Binhai, Dafeng, and Dongtai) and expected to commence in Sheyang in the final quarter of 2013.

2.4 Feed-In-Tariffs

The other major obstacle making developers reluctant to start construction is the overly low feed-in-tariffs. Prior to this first concession round the government had removed a regulation stipulating that the highest and lowest bids would be eliminated from the tender, which had been used to good effect in the early onshore concession rounds. The danger of selecting bids based on price is that it tends to produce extremely low bids. In order to win the concession project, some bidders intentionally underestimate operating costs to get a lower price compared to other bidders. This created a race-to-the-bottom bidding war to win the concession projects, with developers entering bids with low and unprofitable FITs.

One interpretation might be that power companies were keen to impress local and central government with their progress towards developing clean energy sources (Innovation Norway, 2013), while another might suggest that this was in order to gain first-mover advantage over other developers hoping to engage with the offshore industry (Quartz & Co., 2013). However, once such a bid is selected, it proves economically impossible to construct and operate the offshore wind farm, with developers failing to meet the build-out price stated in their concession tender, and construction stalling as a result of their inability to make commercial returns against such a low FIT (Hong & Moller, 2012).

It is unsurprising that developers are unable to make a profit given that the offshore FITs were only ~30% higher than the FITs established for onshore wind power, despite offshore projects typically costing 2-3 times more than those onshore. To help the developers of the first concession round to recoup the substantial investments in their respective projects, the NEA has allowed the four developers to apply for new feed-in-tariffs. For example, China Datang has applied for an increase of FIT from CNY 0.737 to 0.860 per kWh (Takung, 2013). Yet even this revised FIT is below the CNY 1.0/kWh thought to be necessary for developers to make an 8% internal rate of return (IRR) (Wind Power Monthly, 2013).

However, it should be acknowledged that due to the immaturity of the offshore industry in China and the lack of commercial projects in operation, it is still unclear what level of FIT would be most appropriate, and the industry has much to learn before it can confidently establish a long term incentive mechanism. Indeed, the onshore wind industry went through 5 rounds of concession bidding before NDRC established the benchmark FITs and offshore wind has only been through one round so far. Thus, in the absence of a FIT, the Chinese government are likely to go through more rounds of concession tendering. The second round, with a total capacity of 2 GW, was originally planned to commence in 2011 but was postponed in line with the delays to the first concession round. With the first round projects now approved and on track to all begin construction towards the end of 2013, it is anticipated that the second round of concession tenders will open soon, likely in 2014. These 'pilot' projects will provide an opportunity for developers to gain experience in constructing offshore wind farms and provide a testing ground for various offshore wind technologies that can be deployed in China. Experience gained from these projects will help to identify key challenges and understand an appropriate level for a long-term and sustainable FIT (Quartz & Co., 2013).

2.5 Priority Status

China's offshore wind industry has also recently been boosted by the announcement in February 2013 that offshore wind has been given priority status by the NDRC. This affirms the government's commitment to supporting the sector and should result in preferential policies and incentive mechanisms for the industry, as well as better access to funding and faster consenting approval. With equipment manufacturing also explicitly identified in the priority list, the entire offshore wind supply chain can expect to benefit (Quartz & Co., 2013). Importantly, increased support is also expected to result in more favourable FITs to project developers.

2.6 Health and Safety

Despite the offshore wind regulations formulated thus far, very little attention has been paid to health and safety (H&S). China has a relatively poor health and safety record within the wind industry. In 2012, eight deaths out of a global total of 12 in the wind industry (both on and offshore) occurred in China (Wind Power Monthly, 2013b). There is a perception that manufacturers are generally unwilling to reveal their H&S track records or collaborate on H&S issues (Wind Power Monthly, 2012).

In response to this globally poor record, the Chinese government has been perceived as pushing health and safety standards to improve the country's reputation (Wind Power Monthly, 2013b). Turbine manufacturers with international connections also recognise the need for a sound H&S record. Goldwind has invested over CNY 7 million in its safety programmes in China and as of the beginning of 2012, and claims that it has not experienced any major injuries since certifying its management safety systems in 2010 (Wind Power Monthly, 2012).

Financing

As indicated in previous sections of the report, project costs are one of major barriers to scaling up the deployment of offshore wind in China. The investment cost per MW of offshore wind farms in China is estimated to be 1.5-3 times of the same scale onshore wind farms (Hong & Moller, 2012), at around CNY 14,000-19,000/kW (IEA, 2011). For developers to make sufficient returns on their investment (typical benchmark = ~8% IRR), a competitive feed-in-tariff is therefore necessary. The IEA suggests that a reasonable tariff for offshore wind power should be at least CNY 0.30/kWh higher than for coal power, because offshore wind turbines and construction can be much more expensive than for land-based projects (IEA, 2011). However, the FITs established for the initial concession projects (ranging from CNY 0.6235-0.737/kwh) have been deemed too low for developers to make profits.

In July 2012, NEA commissioned China Renewable Energy Engineering Institute (CREEI) to conduct policy research on an offshore wind FIT. CREEI recommended "a stable benchmark FIT mode," which would set different FITs for different groups of areas whose wind resources and construction conditions are different, which is the same practice employed for the onshore wind industry. However, no timeline has been set for the announcement of offshore wind tariffs and, according to a Carbon Trust interview with the National Renewable Energy Research Centre of China, better utilization of onshore wind seems a more imminent priority for NDRC.

Even the Donghai Bridge Project, which benefitted from Certified Emission Credits (CER) under the Clean Development Mechanism (CDM) and has a FIT of CNY 0.978/kwh, is only marginally above the industry benchmark at 10% IRR. Without the CER income it has been estimated that the actual IRR could be just 4.5% (Yu & Zheng, 2011). Considering that the initial concession projects in Jiangsu have FITs ~30% lower than this, it is clear that they will struggle to achieve any financial return, and the result of insufficient financial resources is the long-term delay of offshore wind farm constructions, which has been evident in these projects. Indeed, Hong & Moller (2012) expect that under the current pricing mechanism only 40-70% of the national 2020 target will be achieved (Hong & Moller, 2012).

In order to overcome this issue, the NEA has given permission to the four projects to apply for new FITs (Takung, 2013), although they are unlikely to obtain the CNY 1.0/kwh FIT industry expects is necessary to make profits on these early offshore wind projects (Wind Power Monthly, 2013). For example, China Datang has applied for an increase of FIT from 0.737 to 0.860 CNY per kWh.

The other motivation is to gain first-mover advantage in the nascent offshore wind market. Through gaining first-hand experience of developing offshore wind projects, developers can progress up the learning curve ahead of competitors, and place themselves in an advantageous position to win future concession tenders and larger, more profitable offshore projects further down the line (Quartz & Co., 2013). Indeed, the industry is expected to benefit from this approach as the cost of offshore wind development in China is expected to decrease over time, becoming more cost effective as the industry matures and reaches critical mass. For example, the IEA (2011) expect that investment costs will decrease to CNY 14000/kw in 2020, CNY 12000/kw in 2030, and CNY 10000/kw in 2050 (fig.3.0.1). Together with reduced O&M costs, the level of FIT required will also decrease significantly for near-offshore sites. However, cost reduction through both innovation and learning-by-doing will be integral to this.

Fig.3.0.1. Expected investment costs and feed-in tariffs of typical wind farms in China (2010 prices)

		2010	2020	2030	2050
Unit investment (CNY/kW)	Land-based	8 000-9 000	7 500	7 200	7 000
	Near offshore	14 000-19 000	14 000	12 000	10 000
	Far offshore	-	50 000	40 000	20 000
O&M cost (CNY/kWh)	Land-based	0.10	0.10	0.10	0.10
	Near offshore	0.15	0.15	0.10	0.10
	Far offshore	-	0.30	0.20	0.10
Projected average tariff (CNY/kWh)	Land-based	0.57	0.51	0.48	0.45
	Near offshore	0.77-0.98	0.77	0.60	0.54
	Far offshore	-	>2	2	1

Source: IEA (2011).

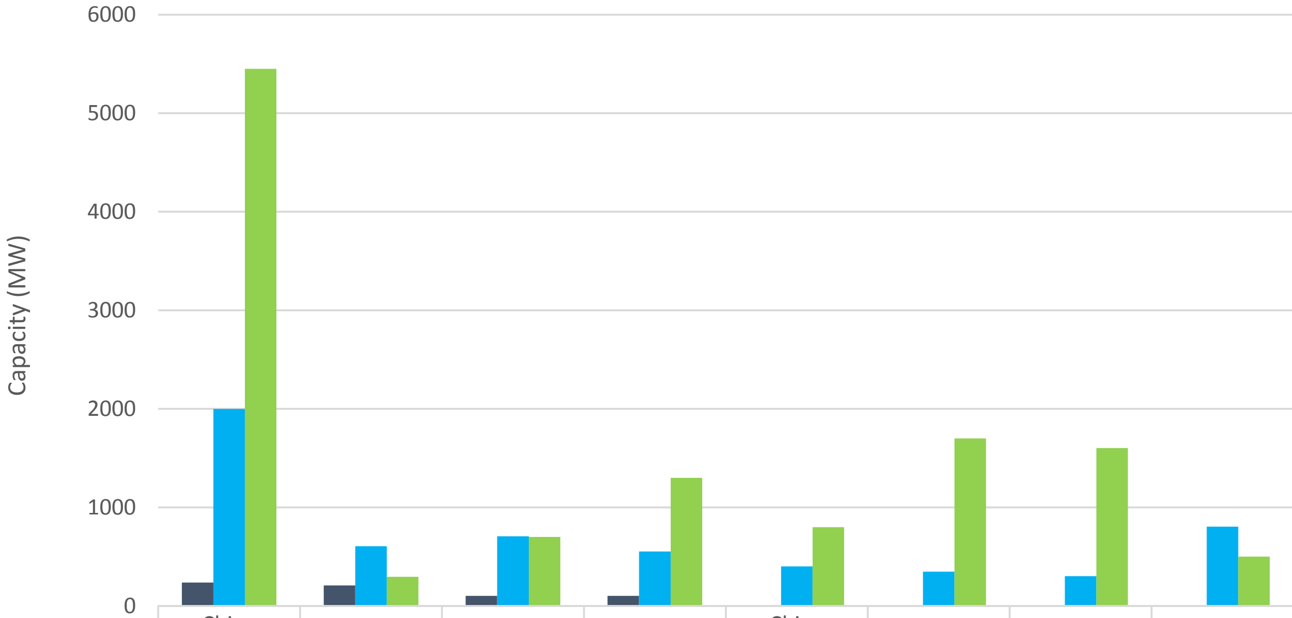
As state-owned enterprises (SOEs), developers benefit from low-cost financing from China's banking sector, particularly through low-interest non-recourse loans. Furthermore, the Chinese Development Bank (CDB) specifically supports the renewable energy sector through its lending, and provincial governments have also been known to support local renewable energy manufacturers (Innovation Norway, 2013). However, Yu & Zheng note that the motivation to invest is not necessarily for profit, but to comply with government targets (Yu & Zheng, 2011). Development of offshore wind in China is mostly conducted by state-owned power companies that are financed by state-owned banks like China Development Bank. Thus the offshore wind industry may be operating less on a market basis but as a centrally planned economy. The level of financing available for SOEs is thought to be sufficient for the next 2-3 years; however, with EUR 120 billion required to construct 30 GW of offshore wind power, more investment will be required from additional sources (Quartz & Co., 2013). Increasing the profitability of offshore projects will encourage investment, while collaboration with foreign companies could also bring in additional revenue.

Wind Farm Developers

4.1 Overview

Offshore wind development in China is largely monopolised by a handful of state-owned utilities, most of which have existing experience from the onshore wind and oil and gas industries. Given the significant investment required and, thus far, limited opportunities for commercial returns, it is unsurprising that offshore wind development is dominated by around 8 cash-rich SOEs (fig.4.1.1), which also benefit from significant support from the Chinese Development Bank (CBD). In addition to the aspiration to get a foothold in one of China's prioritised industries, with a view to making long-term financial returns, state utilities are also bound by legislation under the Renewable Energy Law (REL) to source at least 3% of their energy from non-hydro renewable source; which will increase to 8% in 2020. China Longyuan Power Group, a subsidiary of China Guodian Corporation and the largest onshore wind power producer in China, leads the market by some distance, both in terms of current and planned capacity; and, together, these 8 utilities have cumulatively installed 98% of current capacity, with 5.0 GW already consented and an additional 12.3 GW in the pipeline (fig.4.1.1). Assuming a cost of CNY 13 million per MW installed capacity,[1] total investment in the industry from these top 8 developers can be expected to be in the order of CNY 233 billion to develop these projects (table.4.1.1).

Fig.4.1.1. Capacity for offshore wind developers



	China Longyuan Power Group	China Three Gorges	China Datang Corporation	China Guangdong Nuclear	China National Offshore Oil Corporation	China Huadian Group	Shenhua Group	China Huaneng Group
Installed	238	208	102	102	2	0	0	6
Consented	1999	606	708	552	402	348	302	804
Pipeline	5450	296	700	1301	800	1700	1602	500

*Where developers have partnered on a project, capacity has been counted against each participating developer.

Source: www.4coffshore.com; Carbon Trust analysis.

[1] Based on typical cost of £1.2m/MW to £1.5m/MW for UK Round 1 and 2 projects and China Longyuan investing EUR 1.6 bn to install 1 GW (Quartz & Co., 2013).

Table.4.1.1. China's top 8 offshore wind developers.

Developer	Total planned capacity	Company turnover (EUR millions)	Comments
China Longyuan Power Group (China Guodian Corporation)	7.7 GW	2,075	Plans to use 20% of all equity-raised money to develop offshore wind projects (recently raised EUR 291 million).
China Three Gorges	1.1 GW	N/A	No official targets; but considered one of the most financially secure utilities in China, with significant cash reserves.
China Datang Corporation	1.5 GW	526	Plans to invest EUR 7.4 billion in offshore wind projects.
China Guangdong Nuclear	2.0 GW	N/A	
China National Offshore Oil Corporation (CNOOC)	1.2 GW	21,568	Received EUR 1.7 billion from the Chinese government to develop a 1 GW offshore wind farm in Bohai Bay.
China Huadian Group	2.0 GW	262	Plans to invest EUR 738 million in Jiangsu province alone.
Shenhua Group	1.9 GW	14,724	
China Huaneng Group	1.3 GW	N/A	
TOTAL	17.9 GW		

Source: www.4coffshore.com; Quartz & Co (2013).

Chinese developers have also been keen to establish partnership in various parts of the supply chain, particularly with wind turbine manufacturers. To date, given the industry's nascent level of maturity, projects have been developed using make-shift equipment, particularly regarding vessels and installation equipment. Building and developing a strong supply chain dedicated to offshore wind development is therefore clearly advantageous for developers and partnering with suppliers in the bidding process can strengthen their position when seeking to win new project sites. For example, MingYang has partnered with Guangdong Nuclear Power Group, Huadian Group, and Huaneng Group respectively with plans to co-develop a series of projects using MingYang's 6 MW turbines (4coffshore, 2013).

While, but for a few examples, developers in China tend to operate individually, one joint collaboration with multiple stakeholders has emerged in the industry, similar to those evident in Europe. The South Offshore Wind Joint Development is a joint venture consisting of nine enterprises which aims to de-risk project development and attract higher levels of investment, as well as bringing together players from different parts of the supply chain (Quartz & Co., 2013). The collaboration, which includes China South Power Grid (grid operator), Guangdong Yudean Group (power utility), and MingYang (WTG) – though none of the big eight – has had consent approved for a 198 MW project in Guangdong province, which started construction in May 2013 (4coffshore, 2013).

4.2 Project Consenting Process

Because each province in China has its own master plan for developing offshore wind power, developers usually go to provincial energy administrations and local governments to find out available projects and sign the agreement with them to start preliminary development work. The provincial plans are drafted by appointed investigation and design institutes, and then compiled into the national plan by the Water Resources and Hydropower Planning and Design General Institute, on behalf of NEA. A total of 38 projects, with cumulative capacity of 16.5 GW, are currently performing preparation work.

Although there is no standard practice, wind resource, grid connection and construction conditions are primary factors for developers to consider when evaluating a potential project. Construction conditions is a broad term used by Chinese developers to refers to considerations of traffic, fishery, marine geology, facilities available and construction company's capabilities.

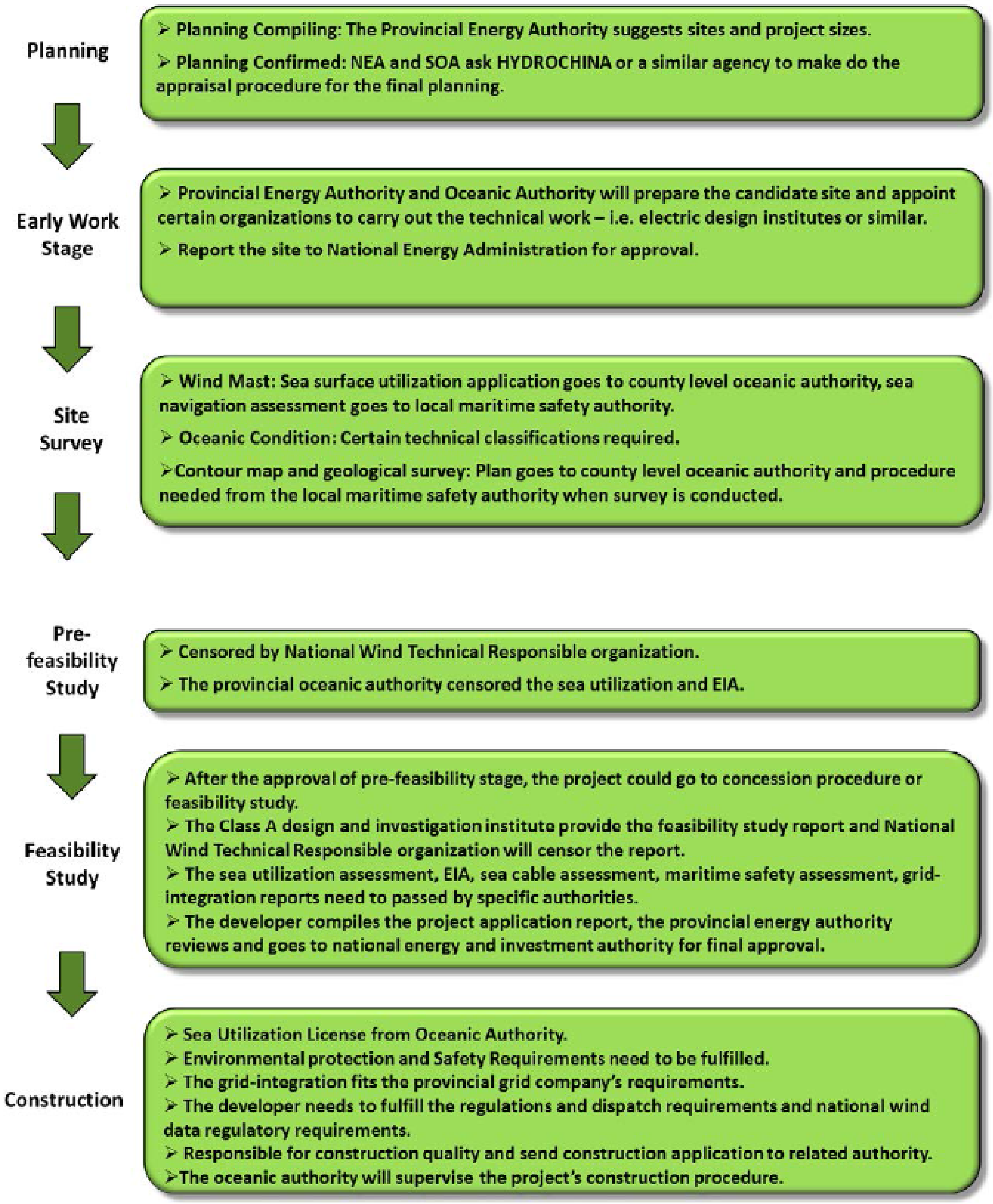
In China's first round of concession bidding, developers had to team up with design institutes, turbine suppliers and construction companies before being eligible to submit a bid. Due to the limited experience in offshore wind in China, developers usually take for reference the practices of Shanghai Donghai Bridge demo project and Longyuan Rudong Intertidal demo project.

It usually takes at least 2 years to obtain full consent from the government to build an offshore wind farm, involving a complex and lengthy process of obtaining approvals from many different administrative departments (fig.4.2.1). Developers will need to obtain approvals from the oceanic administration, maritime safety administration, fisheries, environmental protection department, and military. Before they can proceed to make the final application to NEA, they still need to ask for State Grid's consent to ensure grid connection.

In May 2013, the NEA extended the authority to approve offshore wind project to provincial governments in an effort to endorse the prime minister's call for "reducing central government's consenting rights" and reduce the timeline to gain consenting approval (cnwpem, 2013). However, Carbon Trust interviews with industry suggest that a lack of implementation guidance to local authorities means that the provinces are unable to properly assess the projects; thus, the consenting process has changed little with central government still taking control of offshore wind development.

Concessions are allocated typically for a 25-year period, and provincial grid companies are required to sign a power purchase agreement (PPA) with successful bidders. The price at which electricity is delivered to the grid is fixed during an initial period, typically about 10 years, at a level set during the initial bidding process, with the price in subsequent years expected to adjust to the prevailing electricity market price in the region served by the grid (Xiliang et al., 2012).

Fig.4.2.1. Consenting process for offshore wind development in China.

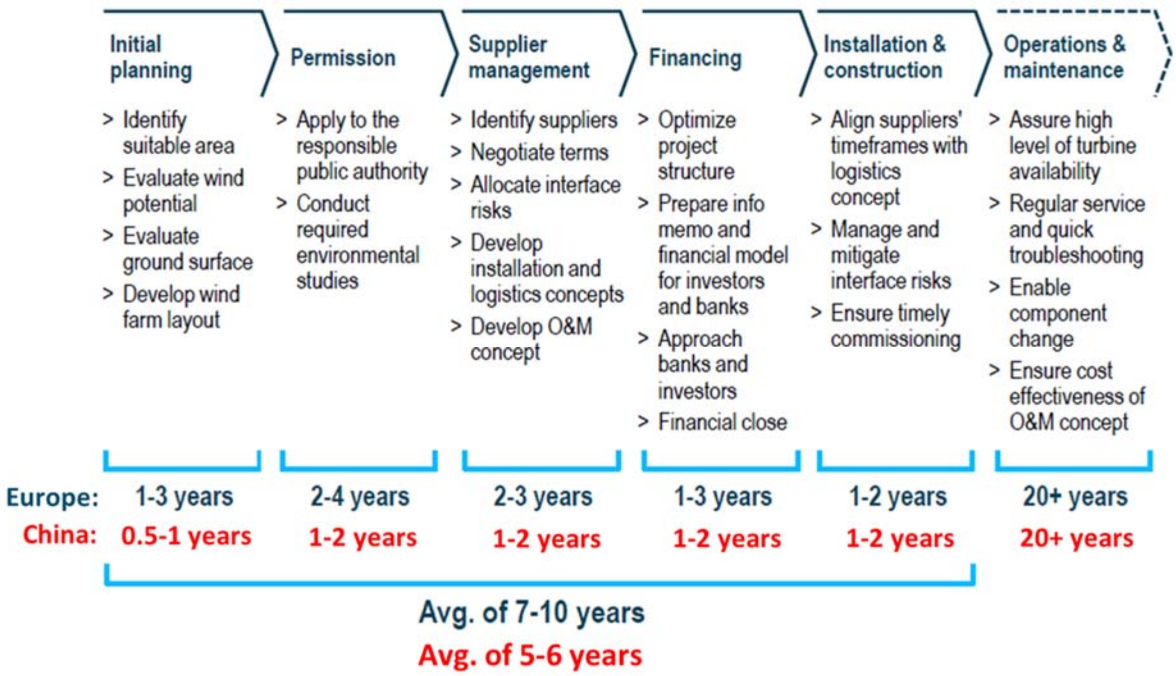


Source: Innovation Norway (2013) – Transition to green energy in China, Japan, and Korea.

4.3 Project Development Timeline

With China's state-owned utilities under pressure to meet national near- and medium-term deployment targets for offshore wind, developers are having to fast track the development of their projects. This is extenuated further by the requirement to begin construction within 2 years of consent approval. Prior to the construction phase, Chinese developers typically aim to complete the preparation of their wind farms 2-4 years quicker than in Europe (fig.4.3.1). If done correctly, this can lead to improved financial returns; however, there are significant risks with such an approach, which can result in the opposite, with reduced yield leading to poor returns. GL Garrad Hassan estimate that 80% of risks are born in the project development phase, prior to construction, particularly in the front end engineering design (FEED) phase, in which appropriate technologies for the project are chosen (GL Garrad Hassan, 2013). Developers in China should therefore take caution when rushing to develop their sites, particularly given their lack of experience in the offshore wind industry to date.

Fig.4.3.1. Project development timeline for a typical offshore wind project in Europe and China.



Source: Adapted from Roland Berger (2013); China timeframes taken from GL Garrad Hassan (2013).

Wind Resource Assessment

Appropriate site selection is critical for the success of the wind farm. Increasing yield is one of the most cost-effective means of improving IRR. For example, it is estimated that a wind turbine at a site with an annual mean wind speed of 9.0 m/s will produce double the energy of a turbine at a site with an annual wind speed of 6.5 m/s (World Bank, 2008). Accurate wind resource measurement to ascertain the power output of a site is therefore crucial before making expensive offshore investments, particularly considering that is represents just 1-1.5% of total project costs (GL Garrad Hassan, 2013).

A related issue that can affect energy production is the wake effect in offshore wind farms, caused by the increased turbulence to the wind passing through the array. The difference in energy production between upwind and downwind rows of turbines can be significant. Assessing the wake effect of a wind farm array should therefore form an important part of the planning process, such that the turbines can be arranged in the most efficient way to maximise energy production.

4.4 Design Institutes

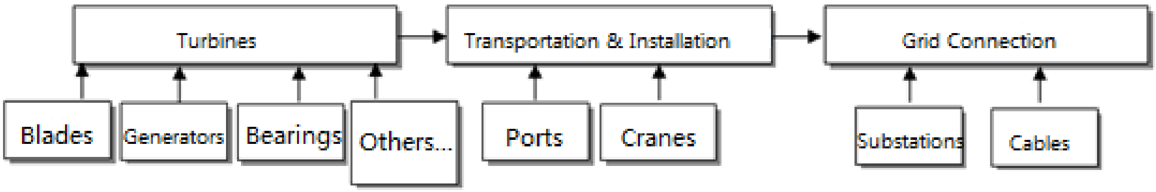
Much of the project development in China is conducted by design institutes, which can play a central role in both the planning and construction phases. Design institutes have a particular focus designing the electrical power system, namely the electrical infrastructure and power transmission system, including turbine array layout, inter-array cabling, connection to sub-station, export cable to shore, and connection to the grid. As part of designing the project, design institutes will also be responsible for the choice and design of technologies used, such as foundation type, and if developers decide upon an EPC contracting model, design institutes can also become responsible for installing these designs and construction of the entire wind farm. This was evident in the Donghai Bridge project, in which Shanghai Investigation, Design & Research Institute (SIDRI) took complete control of the project, responsible for planning, design, and consultation during the tendering stage, as well as overseeing the construction and installation of the turbines and foundations, which was sub-contracted to CCCC Third Harbour Engineering Co.

Hydrochina Huadong undertook a similar role for the Rudong intertidal project, and Guangdong Electric Power Design Institute (GEDI) has been commissioned to develop a number of projects in Guangdong province (Innovation Norway, 2013). Due to the lack of experience in planning, managing, and constructing offshore wind projects in China, design institutes have sought help from European companies. For example, GEDI have agreed a partnership with GL Garrad Hassan, who will hold training courses to up-skill personnel and provide on-going assistance throughout each of its project's development (GL Garrad Hassan, 2013b).

Infrastructure

Offshore wind infrastructure is important for China to realize its development targets for offshore wind. It involves a number of components of the supply chain, including manufacturing, equipment transportation, installation, and grid-connection (fig.5.0.1).

Fig.5.0.1. Infrastructure for offshore wind power development.



Source: CWEA (2013).

5.1 Grid Connectivity and Offshore Cabling

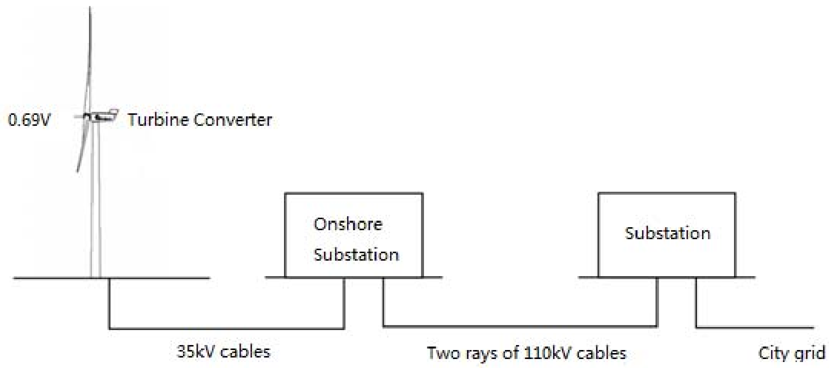
China's onshore wind industry has suffered major issues with grid connectivity. Although China has significant wind resource in its Northern and Western regions, transmitting the electricity to the key demand centres in the East is extremely costly and inefficient. The rapid growth of the onshore industry has been documented, but China's power system is not keeping up with the demand for wind power development, resulting in a number of onshore sites being left idle and unconnected to the grid. However, the power grid infrastructure in the East is fairly well-developed, and is better equipped to handle increased electricity supply from nearby offshore wind farms. Over the past few years, China has constructed one of the most powerful grid systems in the world (IEA, 2011), with advanced technologies and technical facilities to cope with the demands of an increasing electricity supply from a diverse range of renewable sources. A study on wind power integration into the grid conducted by the NEA in 2010 revealed that China could achieve grid connection of 160-200 GW by 2020 (IEA, 2011), in line with the country's wind power ambitions.

The major barrier is connecting the offshore wind farms to the mainland grid. China has little experience of this, particularly beyond near-shore farms, and will need to improve capability quickly in order to cope with the expected growth of the offshore industry over the coming years. The scale of offshore growth and level of grid connection required for gigawatt-scale wind bases, as envisaged in China, has no precedent anywhere in the world, and while this poses a challenge for China, it also presents an opportunity for China to take the lead in the industry.

Sub-stations

Substations are one the most important facilities for connecting offshore wind farms with the central power grid. While China has good experience and capability in building onshore sub-stations, it has yet to install a sub-station offshore. Due to the close proximity of existing offshore wind farms to shore, it makes economic sense to locate the sub-station onshore. Projects installed to date typically transmit the 690V output from the turbines with low-voltage cables (35kV) connecting to an onshore sub-station which increases the flow to 110kV or 220kV before transmitting to a larger sub-station which connects to the grid (fig.5.1.1; table.5.1.1).

Fig.5.1.1. Grid Connection in Shanghai Donghai Bridge Wind Farm



Source: CWEA (2013).

Table.5.1.1. Power Transmission and Grid Connection Methods of China's Several Offshore Wind Farms

Project Name	Wind Turbine's Output Voltage	Voltage of Submarine Cable	Power Transmission and Grid Connection Mode
Shanghai Donghai Bridge Offshore Wind Power Demonstration Project	690V	35kV	690V output voltage of wind turbine is increased to 35kV and then transmitted to 110kV onshore substation through 35kV submarine cables. Onshore substations are then connected to the grid.
Longyuan 30 MW Pilot Intertidal Wind Farm in Rudong, Jiangsu	690V	35kV	690V output voltage of wind turbine is increased to 35kV and then transmitted to 220kV onshore substations through 35kV submarine cables. Onshore substations are then connected to the grid.
Changjiang New Energy Pilot Wind Turbine Project in Xiangshui, Jiangsu	690V	35kV	
Bohai Offshore Power Generation Demonstration Project of China National Offshore Oil Corporation (CNOOC)	690V	10kV	690V output voltage of wind turbine is increased to 6.3kV via the turbine converter and then transmitted to the 6.3 kV power grid of oil rigs via 10kV submarine cables.

Source: CWEA (2013).

However, as offshore wind farms move further from shore, this method will incur significant transmission losses, hence the need to develop offshore substations. China has made efforts to build capability in this area, in terms of both substation design and construction. With regard to the former, some research institutions, such as the Huadong Engineering Corporation, have started research on the marine design of offshore substation; while in terms of project construction, some large enterprises with marine capability have started the construction of offshore wind farm substations, such as China Datang Corporation Renewable Power Co., who has started constructing the "Offshore Wind Farm Substation Project" in Haiyan Economic Development Zone.

Transmission has been connected through Alternating Current (AC) so far, and while DC would improve transmission efficiency further and China has the capability to manufacture appropriate cables, it is isn't expected to be cost effective until farms move to far-offshore sites.

Sub-sea Cables

Due to the close proximity of China's existing offshore wind farms to shore, wind farms have been directly connected to onshore sub-stations to date, using medium voltage cables (35 kV). However, as projects move further from shore they will need to connect to an offshore sub-station and upgrade to high voltage cables (220 kV) in order to reduce transmission losses. However, while there are a number of cable suppliers with capability to supply the offshore industry, only 2 or 3 are able to produce 220kV submarine cables. The clear market leader is Jiangsu Zhongtian Technologies (ZZT), which has provided the cabling for most of China's offshore wind projects so far (table.5.1.2).

Table.5.1.2. Cables used by some of China's offshore wind projects.

Project Name	Installed Capacity	Submarine Cable Model	Size (mm^2)	No. of Optical Fibre Cores	Manufacturer
CNOOC Bohai Offshore Power Generation Demonstration Project	1.5MW	ZS-YJQF41 + OFC1-8.7/15	3 * 150	12	ZTT
Donghai Bridge Offshore Wind Power Demonstration Project	100MW	HYJQ41 + OFC-26/35	3 * 3 * 70 ~ 300	36	Qingdao Hanhe
Longyuan 30 MW Pilot Intertidal Wind Farm in Rudong, Jiangsu	30MW	ZS-YJQF31 + OFC1-26/35	3 * 3 * 70 ~ 150	24 36 48	ZTT
Changjiang New Energy Pilot Wind Turbine Project in Xiangshui, Jiangsu	4.5MW	ZS-YJQF41 + OFC1-26/35	3 * 50	18	ZTT

Source: CWEA (2013).

ZZT currently produces a variety of submarine cables, including submarine optic/electric composite cables and has developed a production capacity of 8,000 km per year for optic/electric cables. Assuming a requirement of 0.5 km of cabling per megawatt, China is expected to need 15,000 km over the next 6-7 years to meet its deployment targets. While ZZT alone appears to have sufficient production capacity to fulfil this goal, without competition in the market, the price of cables is expected to remain high, with the offshore wind submarine cable market currently estimated at CNY 18 billion.

A likely interpretation of the lack of suppliers of 220kV cables is the current shortage of demand from the offshore wind industry, rather than necessarily a lack of manufacturing capability. The quality of domestic cables is on par with international suppliers (Quartz & Co., 2013), and Chinese companies are able to leverage experience from supplying cables to the oil and gas and telecommunication industries. Particularly given the size of the prize, it is likely that more suppliers will enter the 220kV market as deployment ramps up.

A more critical issue with regard to sub-sea cabling is the shortage of bespoke cable installation vessels, which could pose a serious bottleneck in the supply chain. Offshore wind power has stringent requirements for cable laying and China lacks capacity to meet modern project requirements using specialized submarine cable ships and deep laying equipment. See section 6.3 on cable installation for more information.

5.2 Ports

Port infrastructure is integral transporting and installing offshore wind power equipment. China has a coastline of 18,000 km and a long maritime history, providing strong capability for building large ports. China has developed large and concentrated port clusters in five regions; namely, Yangtze River Delta, Pearl River Delta, Bohai Sea, southeastern coast and southwestern coast; while there are also stretches of ports clusters which have been established along the Yangtze River, Pearl River, Heilongjiang, Huaihe River System and Beijing-Hangzhou Grand Canal. By the end of 2012, China had 31,862 port berths for production purposes (CWEA, 2013b).

China currently has no specialized ports for offshore wind development, and turbine transportation and installation has thus far been conducted from re-configuring existing ports and coordinating activities with other port functions. During the industry's formative years, this is likely to continue as the prevailing strategy; however, as deployment is scaled-up beyond 2015, there will be increasing need for bespoke port facilities. Indeed, several Chinese wind power enterprises are constructing, or plan to construct, large ports to expand their operations, and with close 10 GW capacity planned for the area by 2020, Jiangsu has already been identified as a prime location to develop port infrastructure for the offshore wind industry. For example, Sinovel Wind (Jiangsu) Harbor Co., Ltd started construction on a wind power port in Sheyang Port, Yancheng in September 2010 (fig.5.2.1). The project has a total investment of CNY 5.0 billion and aims to build three 5,000-ton wind turbine shipment berths, one 5,000-ton auxiliary berth, and two workboat berths with a total berth length of 588m. Another wind power manufacturer – Goldwind Science and Technology Co., Ltd – is also building an offshore wind power development base in Dafeng, Jiangsu, to prepare for the future development of the offshore wind industry.

Fig.5.2.1. Location of Sinovel's offshore harbour bases in China (red stars).

*Blue stars = Sinovel branches; blue dots = Sinovel wind farms.

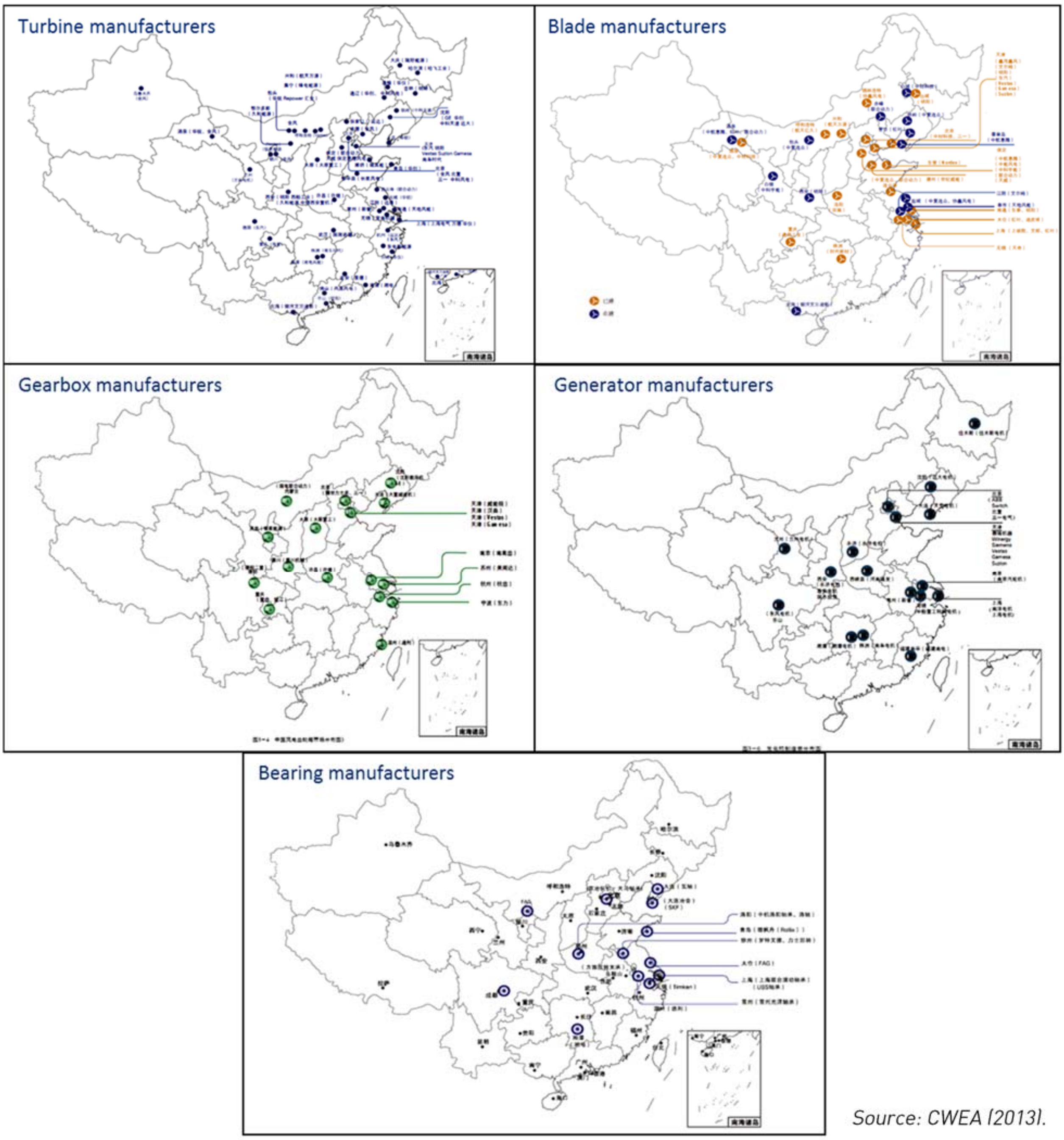
Source: Sinovel (2013).

5.3 Manufacturing

Turbines

Over the past decade, China's onshore wind industry supply chain has been established and steadily improved, covering technology R&D, component manufacturing, turbine assembly, testing, and certification, wind farm development, and other associated services (IEA, 2011). The offshore wind industry, on the other hand, is far more nascent, and the supply chain is currently yet to be fully established. However, many turbine manufacturers will be able to leverage their existing onshore production bases, particularly those close to the east coast (fig.5.3.1). For example, there are only three manufacturers in the world that can produce suitable bearings for offshore turbines, one of which is located in Wafangdian, Liaoning, and contains two of the highest precision machines in the world for bearing manufacture (CNTV, 2013).

Fig.5.3.1. Onshore wind production bases in China.



Source: CWEA (2013).

To improve the efficient competition of wind power equipment manufacturing industry, the Ministry of Industry and Information Technology (MITT) drafted the Access Standard of Wind Power Equipment Manufacturing Industry which contained the following key regulations for manufacturers:

- The equity proportion of initial investment of wind power projects should be no less than 30%.
- Manufacturers should locate their factories near the "wind base" and upstream suppliers to reduce logistical costs.
- Manufacturers should have a unit production capacity of 2.5 MW or more, and cumulative annual production more than 1 GW;
- Manufacturer should give R&D priority to the development of independent intellectual property rights for wind turbines with unit capacity of 2.5 MW or more and the development of offshore wind power equipment.

Only ~10 turbine manufactures in China qualify according to this criteria, particularly the demand to have production capacity of 2.5 MW or more independently, and annual production more than 1 GW (Xiliang et al., 2012). It is therefore expected that the standard will limit the opportunity for small manufacturers to enter the offshore wind market, with manufacturers only selected from the top 10 manufacturers.

Table.5.3.1. Types and production capacity of the top 10 turbine manufacturers in China (onshore and offshore)

Manufacturer	Turbine Type (MW)	Annual Production(MW)	Technology Source
Sinovel	1.5/3/5	3000	1.5 MW: Introduced from Fuhrlander 3.0/5.0 MW: Introduced from Windtec
Goldwind	0.6/0.75/ 1.5/2.5	2200	0.6MW: Introduced from REPower 0.75MW: Introduced from Jacobs 1.5/2.5MW: Introduced from Vensys
XEMC	1.5/2/5	2100	1.5/2MW: Introduced from TMPA 5MW: Introduced from Darwind
Dongfang	1.5/2.5/3	2000	3MW: Introduced from Moventas
Guodian	1.5/3	1000	1.5MW: Co-designed with Aerodyn
Zhongchuan	0.85/2	1000	0.85MW: Introduced from Frisia 2MW: Co-designed with Aerodyn
Mingyang	1.5/3	1000	1.5MW: Co-designed with Aerodyn
Suzlon	1.25/1.5	900	Independent R&D
Vestas	0.85/2.0	800	Independent R&D
Huayi	0.75/1.5	800	0.78MW: Independent R&D 1.5MW: Co-designed with Aerodyn

Source: Xiliang et al. (2012).

Foundations

Foundation manufacture is conducted by large marine engineering companies who have large manufacturing facilities and can leverage capability from producing similar structures for the oil and gas industry. Examples include Jiangsu Longyuan Zhenhua Marine Co.; China Offshore Oil Engineering Corporation (COOEC); Nantong Ocean Water Conservancy Engineering Co. (NOWCE); CCCC Third Harbour Engineering.

Vessels

As with foundations, vessels are manufactured by large marine engineering companies. China has a well-established shipping industry and many of these companies have large shipyards capable of producing a range of vessels. Examples include COSCO Nantong Shipyard; China Shipbuilding Industry Corporation (CSIC); Yantai Raffles Shipyard Co.; Jiangsu Jiaolong Heavy Industry Group (JHI); CSSC Chengxi Shipyard Steel Construction Department; Shanghai Taisheng Wind Power Equipment Co.; Zhejiang Kailing Shipyard.

Submarine cables

There are a number of submarine cable manufacturers in China, including Zhongtian Technology Submarine Cable Co.,Ltd. (ZTT), Hengtong Group Co., Ltd., Huawei Technologies Co., Ltd., Qingdao Hanhe Cable Co., Ltd. While ZTT currently leads the market for 220kV cables, other suppliers are thought to have the manufacturing capability to develop these cables as demand in the industry picks up.

Technology

While China's onshore wind industry is reaching a fairly mature level of technological development, offshore wind is far more nascent, with significant scope for innovation to reduce costs, in addition to improving capability through learning-by-doing. RD&D is therefore crucial to progress the technology, improve reliability, and thereby reduce risk for investors. There are currently ten wind power R&D facilities in China, three of which are dedicated to offshore wind (table.6.0.1). Together, these cover most of the relevant technical elements of wind power development, such as turbine blades, generators, control systems, offshore technical equipment, offshore wind power projects, wind farm operation, wind power grid-connection, and certification (GWEC, 2012). However, there is significant scope to bridge the current technology gap between the offshore industry in China and Europe. The following sections consider the key barriers to scaling-up deployment.

Table.6.0.1. Existing wind power research facilities in China.

Name of research institution		Backing unit
Institutions approved by the Ministry of Science and Technology include	State Key Laboratory of Wind Power Equipment and Control	Guodian United Power Technology Company Limited
	National Engineering Research Center of Offshore Wind Power	CSIC (Chongqing) Haizhuang Wind Power Equipment Co. Ltd.
	State Key Laboratory of Wind Power Generation Systems	Zhejiang Windey Co., Ltd.
	State Key Laboratory of Offshore Wind Power Generation Technologies and Inspection	XIANGTAN ELECTRIC MANUFACTURING GROUP (XEMC)
Institutions established with approval of the National Energy Bureau include	National Energy Wind Power Blades R&D (Experimental) Center	Institute of Engineering Thermophysics, Chinese Academy of Sciences
	National Energy Offshore Wind Power Technical Equipment R&D Center	Sinovel, Shanghai Jiao Tong University
	National Energy Large-Scale Wind Power Grid-Connecting System R&D (Experimental) Center	State Grid Corporation of China
	National Energy Wind Power Generator R&D Center	XEMC Xiangtan Electric Research Institute of Traction Equipment, etc.
	National Energy Wind Power Operation Technology R&D Center	China Guodian Corporation, China Longyuan Power Group Corporation Limited
	National Energy Key Laboratory of Wind Energy & Solar Energy Emulation and Inspection Certification Technology	China General Certification Center

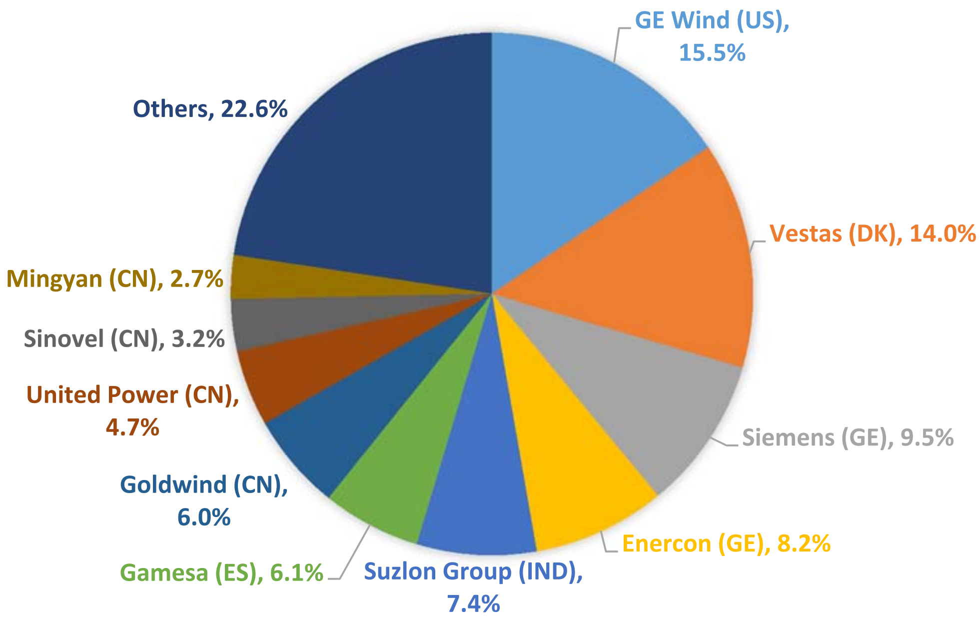
Source: GWEC (2012).

6.1 Turbines

Market Trends

The rapid growth of China's onshore wind industry has built significant capability in wind turbine manufacture, with Chinese manufacturers accounting for over 15% of the global market in 2012 (fig.6.1.1). However, a down-turn in orders for onshore turbines and the increasing demand for offshore turbines has encouraged a number of turbine OEMs to enter what is perceived to be a less competitive offshore market, developing turbines specifically for the offshore industry. However, onshore turbines are typically low capacity (~1-2 MW) and Chinese products have suffered reliability issues in recent years, developing a reputation for low cost, low quality turbines. Offshore wind turbines have more stringent requirements with regards to their technical performance, partly due to the increased costs of conducting maintenance and repairs on turbines many kilometres offshore, and also due to the more complex loads from higher wind speeds, greater risk of corrosion, and risk of damage from typhoons. Thus, while there is potential to transfer capability from onshore to offshore turbine manufacture, there are significant challenges to increasing the capacity and reliability of turbines.

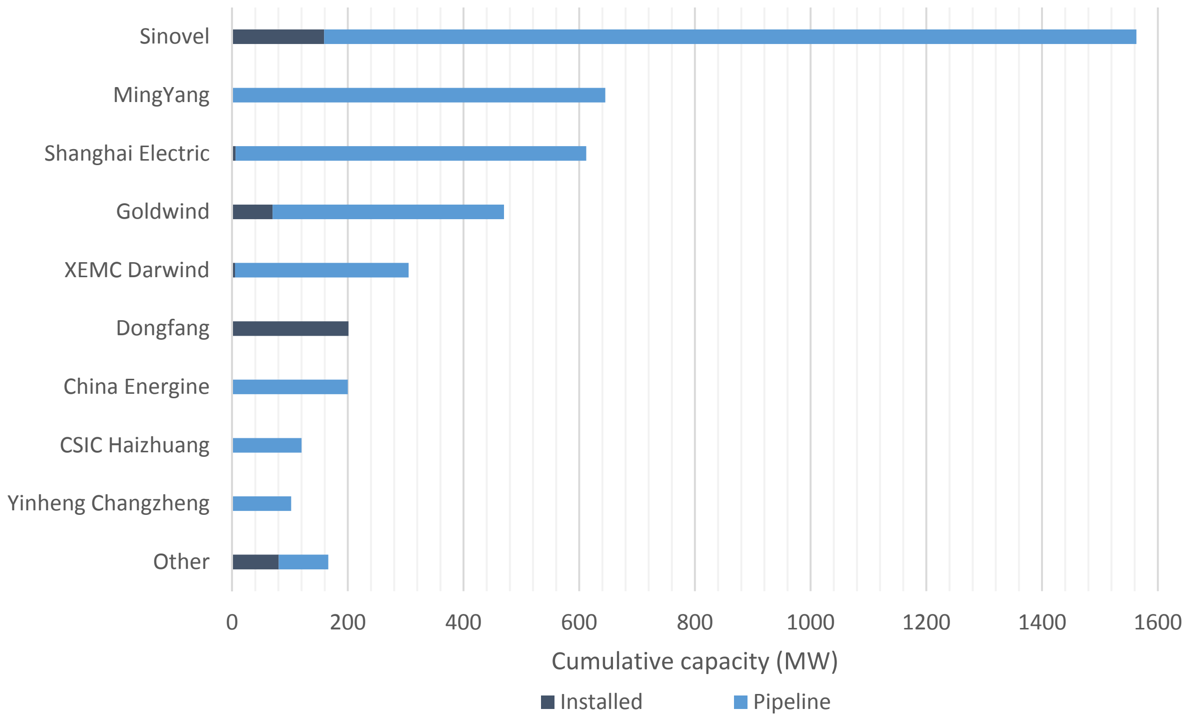
Fig.6.1.1. Top 10 wind turbine suppliers (global) in 2012 as % of total market.



Source: CWEA (2013).

The significant ambition for offshore wind growth in China means that there is a huge market for offshore turbine manufacture. There are already plans from consented sites for over 2,600 turbines (4coffshore, 2013), and potentially up to 6,000 if China is to achieve 30 GW installed capacity by 2020. A number of Chinese turbine manufacturers are now developing turbines for offshore wind development. Current installed capacity is dominated by Sinovel (44%) and Goldwind (28%) (fig.6.1.2). However, MingYang and Shanghai Electric are also developing strong pipelines of installations. The limited number of players is no different to Europe (that Is dominated by Siemens and Vestas0 as developers need confidence in the OEM to deliver turbines to large projects and have a sufficiently large balance sheet to cover losses in case of technical problems. Developing large sites using smaller OEMS can leave developers exposed to risk.

Fig.6.1.2. Cumulative Chinese offshore turbine capacity (MW) by manufacturer (installed & planned).

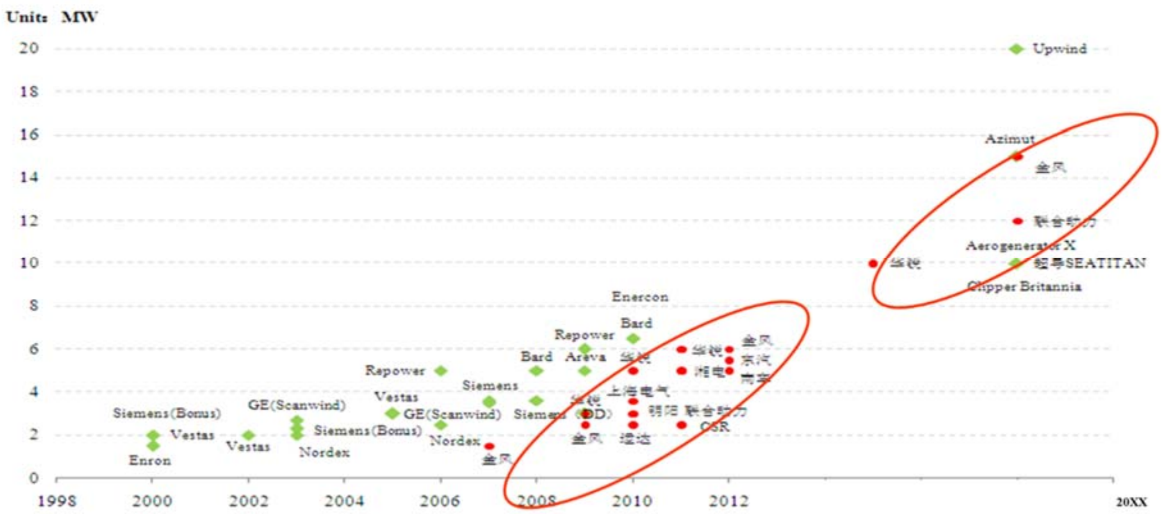


Source: www.4coffshore.com; Carbon Trust analysis.

Turbine Size and R&D

While the majority of turbines currently installed offshore are ~3 MW capacity, a number of manufacturers are hoping to develop larger turbines for offshore projects and there are a number of prototype demonstrations of 5 MW and 6 MW turbines currently being tested, with a view to deploying these at scale beyond 2015 (fig.6.1.3). A variety of new turbine technologies are being designed, including geared and gearless drive-trains, as well as doubly-fed, permanent magnet, and super-conductive generator technologies (table.6.1.1). United Power has already deployed a 6 MW prototype turbine in Shandong, while Sinovel are currently constructing a 102 MW capacity wind farm consisting of 17 6 MW turbines in Shanghai as an extension to the Donghai Bridge wind farm. Meanwhile MingYang has plans to deploy 116 6 MW turbines in Jiangsu (4coffshore, 2013).

Fig.6.1.3. Offshore wind turbine capacity (Chinese manufacturers in red)



Source: CWEA (2013).

Table.6.1.1. R&D advances of some Chinese enterprises in high-power offshore WTGs

Supplier	Rated capacity*	Details	Technology source	Status/plans
CSIC Haizhuang	5.0 MW	Geared, permanent magnet	Proprietary	Two units installed in Jiangsu Rudong intertidal zone in 2012
Dongfang	5.5 MW	Geared, full-power conversion; high-speed permanent magnet	AMSC Windtec	Prototype produced in July 2012; installed in Jiangsu Rudong in May 2013
Envision	3.6 MW	Direct-drive, two-blade, partial pitch	Danish research arm	• 3.6 MW prototype produced in January 2012 in Denmark • 4.0 MW prototype connected to grid in Jiangsu Rudong in late July 2013
	4.0 MW	Geared		
Goldwind	6.0 MW	Direct-drive, permanent magnet	Vensys	• 6.0 MW prototype completed. • Mass production planned in 2014. • 10.0 MW R&D started in 2012; prototype to be produced in 2015
	10.0 MW			
HEAG	6.0 MW	Geared, doubly-fed	MECAL B.V.	R&D started in May 2011
Sinovel	5.0 MW	Geared, doubly-fed	Proprietary	• 5.0 MW connected to grid in Shanghai Songhai Bridge offshore farm in 2011 • 6.0 MW connected to grid in Jiangsu Sheyang offshore zone in 2011 • 10.0 MW R&D started in 2012
	6.0 MW			
	10.0 MW			
United Power	6.0 MW	6.0 MW doubly-fed 12 MW super-conducted, direct-drive	Proprietary	• 6.0 MW prototype connected to grid in Shandong Weifang offshore farm in Jan. 2013 • 12 MW R&D started in 2012
	12.0 MW			
XEMC	5.0 MW	Direct-drive permanent magnet	Darwind	One prototype installed in the Netherlands in 2011, another prototype installed in Fujian Fuqing offshore farm in 2012
Windey	5.0 MW	Geared permanent magnet	Aerodyn	R&D started in 2011
Mingyang	SCD6.0/6.5	Geared permanent magnet, two-blade	Aerodyn	Prototype produced on 28 June 2013 to be installed at Longyuan's offshore wind farm in Rudong
Sany	6.0 MW	Doubly-fed	Proprietary	R&D started in early 2012
SEwind	6.0 MW	Doubly-fed	Siemens	Under development; prototype to be installed in 2014

Note: *Grey=prototype produced; green=under development

Source: IHS (2013)

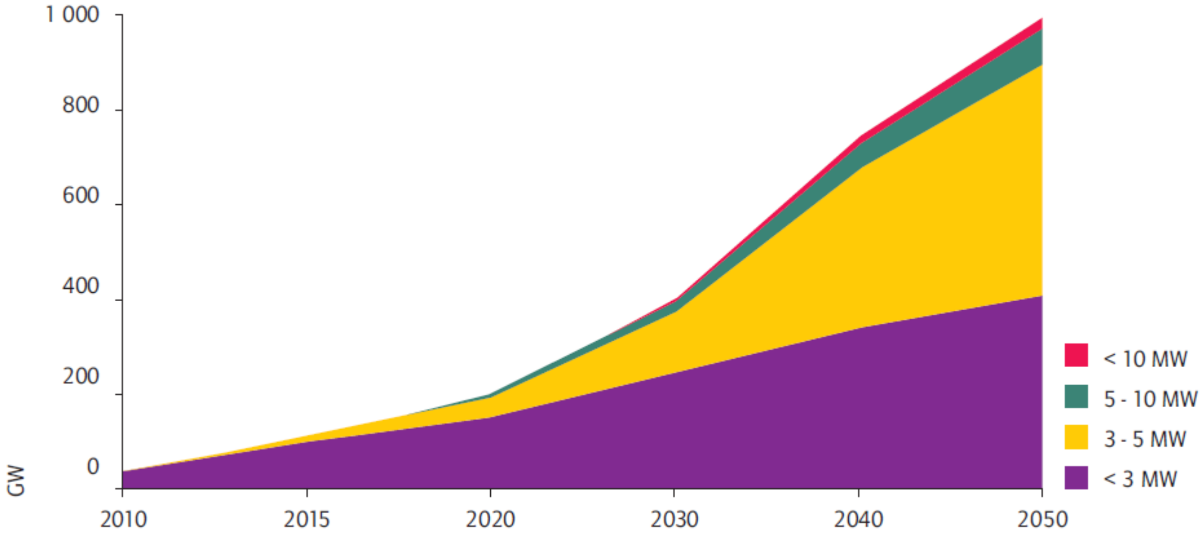
Chinese OEMs have traditionally done little innovation internally, with the capability to develop these lower capacity offshore wind turbines largely coming from licensing the technologies of foreign design companies. For example, Sinovel collaborated with AMSC to design the 3 MW turbines used in the Donghai Bridge project, for which Sinovel retained the intellectual property (IP) rights, and Goldwind has imported its direct-drive technology from Vensys, the German company in which Goldwind now has a 75% stake (Goldwind, 2013).

Government regulation has also encouraged collaborations with European companies. The concession programme criteria mandate that any foreign companies must partner with Chinese firms in order to enter the offshore wind market and, together with increasing emphasis on technical capability in the selection criteria, it is hoped that this will foster collaborations that benefit both Chinese and European players, with the former gaining technical knowledge and the latter gaining access to what is expected to soon become the world's largest offshore wind market. For example, Siemens and Shanghai Electric (aka "SEWind") formed a joint venture in 2011, leveraging Siemens' technology and offshore experience to combine proven European technology with local project management experience. The JV has already secured significant orders for offshore turbines, including orders for the 102.2 MW Donghai Bridge Phase II project (28 x 3.6 MW model), the 201.6 MW Jiangsu Dongtai intertidal project (56 x 3.6 MW), and the 302.4 MW Dongtai wind farm (phase 3; 84 x 3.6 MW) (4coffshore, 2013). In addition, the venture recently announced plans to sell 75 units of its 4 MW turbine in 2014 with the aim to double this figure in 2015 (SeeNews, 2013), further illustrating how joint ventures leveraging a Chinese presence with a European track record can penetrate an emerging market segment.

However, while Chinese companies have done little innovation focussed on offshore wind to date, since acquiring IP for a range of concepts there is a growing trend for OEMs to conduct more R&D internally, with over 70% of the top 15 Chinese manufacturers deciding to develop their own offshore turbines in-house. For example, Guodian United Power claim that their new 6 MW turbine contains entirely independent intellectual property. The company developed the turbine by borrowing technology from its existing turbines, as well as experience accumulated from operating a total of 3,000 turbines in the onshore industry (Xinhuanet, 2012). However, most OEMs continue to invite foreign consultancies to evaluate and verify their designs (Goldwind, 2013).

With 5 and 6 MW turbines on the verge of being commercially available, R&D is now increasingly focussing on developing larger 10+ MW turbines. The Chinese government has explicitly outlined a target to produce a 10 MW turbine by 2015 in its latest Five Year Plan and has awarded a EUR 5.2m grant to Sinovel in pursuit of this goal, which Sinovel has matched with EUR 34.5m of its own funding (Quartz & Co., 2013). The company is currently building a National Energy Offshore Wind Technology and Equipment R&D centre with government, which will be able to test wind turbines up to 15MW capacity and blade length of 120m (Sinovel, 2013). Goldwind has also started R&D at its testing facility for a 10 MW turbines (Goldwind, 2013), and United Power has recently started R&D on a 12 MW turbine (4coffshore, 2013). However, it is unlikely that these will be deployed on a large scale before 2020, with 3-6 MW turbines expected to dominate the market over the next decade (fig.6.1.4). Indeed, the IEA expect that 5+ MW offshore turbines will have an annual demand of 1.0-1.3 GW between 2015 and 2020, increasing to an annual demand of 22 GW from 2020 to 2030 as deployment is scaled up further (IEA, 2011).

Fig.6.1.4. Megawatt-scale turbine system demand in China, 2010-50 (onshore and offshore).



Source: IEA (2011).

Supply Chain Structure

In the onshore industry, increased vertical integration in the design phase has been paralleled with a more vertically integrated supply chain, in which OEMs make their own auxiliary parts and components, resulting in a complete-machine manufacturing process (GWEC, 2012). However, this is not yet being replicated in the offshore industry. Thus while companies such as Goldwind and Sinovel are all developing and producing parts and components for their onshore turbines; it appears that, for offshore turbines, the same manufacturers continue to outsource most components, with a diverse range of suppliers to protect against problems in the production line. In fact, Goldwind is planning to increase the number of components it imports from abroad to 50%, particularly high quality downstream components, such as control systems and power converters, which Chinese turbine manufacturers are unable to produce locally (Quartz & Co., 2013).

However, there has been more upstream-downstream integration with regard to project development. While OEMs do not have sufficient capital to construct commercial scale wind farms by themselves, some turbine manufacturers have opted to co-develop projects with power companies, usually with some initial demonstration projects followed by large scale project development if their technology proves successful. This enables OEMs to test their turbines at the demo stage and strengthen its position to win large follow-on orders. This strategy is particularly evident with MingYang, who has partnered with Huadian Power and China Huaueng Group on two different offshore projects currently at the early planning stage, consisting 400MW and 300MW respectively (4coffshore, 2013).

Technical Challenges

China will require a significant amount of R&D to master the design methodologies and technology advances needed to develop sophisticated large turbines, particularly those which are tailored to China's specific wind farm characteristics. Namely, China's offshore turbines will need to focus on reliability, cost-effectiveness, structural integrity, ease of transportation, maintenance, and greater resistance to typhoons.

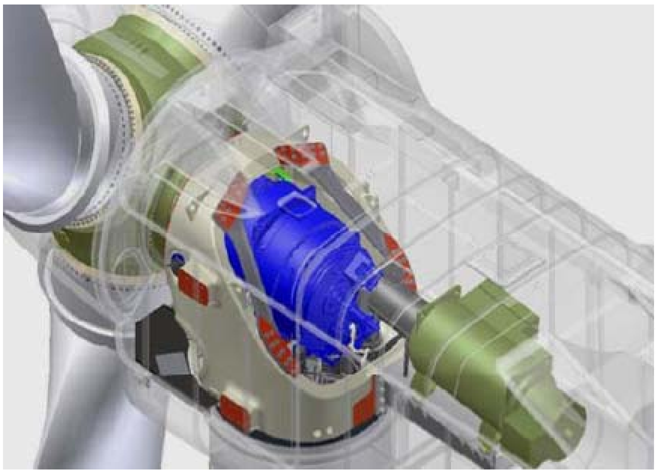
Gearbox:

Gearbox reliability has proved a huge challenge in China's onshore industry, and is likely to be a key focus for companies developing offshore turbines, particularly considering the increased costs of repairing a gearbox at sea. Chinese OEMs have made great strides in improving the reliability of onshore turbines, but larger offshore turbines will require more advanced gearbox technology, hence the need to focus research and innovation to improve bearing life, bearing capacity, and reliability. The nature of variable wind speeds means that the gearbox is subjected to unpredictable force variations, with bearings in particular subject to significant torque. Removing the gearbox from the design by switching from geared to direct-drive turbines (connecting the generator directly to the main shaft) is a potential solution. Alternatively, a hybrid solution is to use a smaller and faster rotating generator with a simpler gearbox and reduced gearbox ratio.

There is a currently no consensus on whether geared or direct-drive is the right path for China's turbine manufacturers. Geared turbines are a more mature and commercialised technology, and currently represent ~80% of the market (Sinovel, 2013b). However, as turbines size increases, direct-drive is anticipated to prove to be a more reliable long-term alternative.

Sinovel favour geared turbines, 34 of which have been deployed in the Donghai Bridge offshore wind project (3 MW unit capacity). In order to cope with additional stresses on larger turbines It has created a compact drive chain with load distribution technology (fig.6.1.5), which reduces the impact load damage and optimises the power transfer capacity, whilst also increasing turbine reliability and operation lifetime. Sinovel have claimed reliability of 96-97% in the Donghai Bridge turbines, and attribute this to the level of care taken to manufacture China's first commercial-scale offshore wind turbines (Sinovel, 2013b). It is therefore unclear as to whether this level of reliability can be replicated when manufacturing is scaled up.

Fig.6.1.5. Compact drive chain and load distribution technology design in a Sinovel turbine



Source: Sinovel (2013).

Goldwind, meanwhile, have opted to adopt the more nascent direct-drive technology. While direct-drive systems are larger and heavier than geared alternatives, they are expected to improve reliability due to fewer moving parts in the nacelle. Goldwind has countered the greater difficulty of transporting the larger and heavier direct-drive units by manufacturing the nacelle next to a canal, allowing it to be shipped directly to the port or project site. Goldwind have installed 20 of its 2.5 MW turbines in the Jiangsu Rudong intertidal wind farm, and has orders to install an additional 160 turbines, with 80 in both Jiangsu Dafeng and Dafeng intertidal wind farms respectively (4coffshore, 2013). Reliability in Jiangsu Rudong is claimed to have recently reached 95%, with fine-tuning and learning-by-doing the source of improvement (Goldwind, 2013).

While progress appears encouraging so far, ensuring that reliability is consistently at least 95% availability is a critical challenge for the industry if it is to increase investor confidence and become cost competitive with other energy technologies, particularly as turbines increase in size. For example, Sinovel anticipate that 10+ MW turbines may require an entire re-design of the whole drive-train (Sinovel, 2013b). Low rates of availability will have a direct impact on yield and require repairs and maintenance further offshore that will increase costs. Developers are therefore likely to favour higher quality and performance over price.

Generator:

Particularly as manufacturers shift towards gearless, direct-drive turbines, the performance of the generator will become increasingly important. Switching to direct-drive turbines creates additional challenges for the generator due to the increased complexity of design, number of poles, and cost of the components (namely, magnets produced from rare earth metals) (LORC, 2013). While doubly-fed and permanent magnet generators are currently most common, superconducting technology is expected to improve performance in the long-term.

The generators used in Sinovel's 3 MW turbines used in the Jiangsu Rudong intertidal project have already experienced problems. Rusting in the nacelle led to failures in a number of components, requiring the generators to be replacement after just one year, which reduced the overall availability to just 80%. While improving the nacelle sealing can mitigate this risk, reliability and ease of maintenance can be improved through the use of more modular designs (IEA, 2011).

As technology breakthroughs reduce the costs of superconducting materials, these generators are expected to increase their share of the market and improve the efficiency of generators, particularly in larger turbines, thereby increasing their cost-effectiveness. United Power's proposed 12 MW turbine, currently undergoing R&D, hopes to use a superconducting generator. Furthermore, while 3-5 MW turbines will use mid-voltage generators, higher capacity turbines will need high-voltage generators, which also require more R&D before they are ready for commercial deployment.

Blades:

Most blades used in Chinese turbines are glass fibre, and there are more than 50 blade manufacturers based in China capable of providing these (Innovation Norway, 2013). However, as turbine capacity increases, so too will the blade length, which will add increasing stresses to the nacelle and entire turbine structure. While the average rotor diameter for 3 MW turbines is ~100 metres, this will need to increase to ~140-150 metres for 5 and 6 MW turbines, and greater yet for 10 MW turbines. Reducing the load and weight of the blades will therefore be critical to ease the pressure on the tower and maximise energy conversion. R&D in alternative blade materials such as carbon fibre and high-intensity fibre glass will support this area. Optimising blade design for improved performance will also be a central focus of R&D activity. As blade length increases, the slower will be the tip speed of the blades and associated rotor shaft speed. Offshore turbines are targeting higher tip speed blades from 80 to 120 m/s (LORC, 2013).

Some turbines manufacturers have also moved to two-blade turbines in order to reduce the weight and amount of stress placed on the nacelle, despite the reduction in efficiency compared to three blade designs. Envision has developed a 3.6 MW direct-drive two-blade turbine and MingYang has produced a 6 MW geared two-blade turbine, which is due to be installed at Longyuan's offshore wind farm in Rudong.

Given China's meteorological conditions, resistance to typhoons is another vital criteria for blades. While control systems to adjust the pitch and yaw of blades can help, the integrity of the blade itself must be able to withstand significant stresses during typhoon conditions. For example, a recent typhoon in Guangdong province damaged the blades of 17 turbines in the Honghaiwan onshore wind farm, near the coastal Shanwei City, resulting in a CNY 100 million loss to the wind farm (Wind Action, 2013).

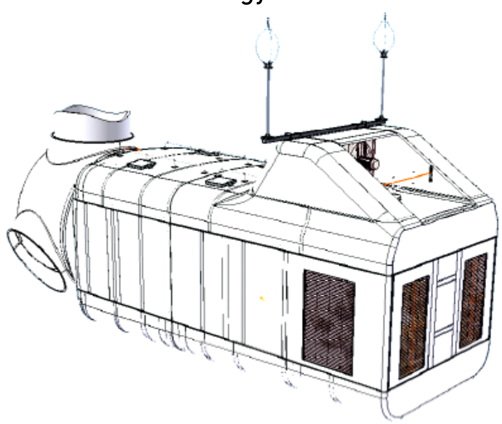
Tower:

In parallel with increased blade length for higher capacity turbines, tower height will also increase. 2-3 MW turbines typically have a tower height of ~60-80m, but as capacity increases to 5-6 MW turbines, the tower will likely increase to 90m+. As well as increasing in height, the tower is likely to be under increasing stress from the increased size and weight of the nacelle and blades. Research into more careful load computation will therefore be required as turbine size increases, particularly considering the threat of damage from typhoons.

Corrosion and over-heating:

A number of existing intertidal and offshore wind projects in China have reported issues from corrosion, something which is unique to China's coastal characteristics. As noted above, rusting in a series of Sinovel turbines in Jiangsu Rudong caused failures in a number of components, reducing availability to just 80%. Current anti-corrosion technology solutions imported from Europe cannot meet the actual geographical and climatic conditions in China; thus significant R&D will be required in anti-corrosion technologies that can extend the lifetime of offshore wind farms to 20 years or longer (IEA, 2011). Sinovel has already made strides here, designing a special nacelle seal structure for turbines installed in the Donghai Bridge offshore project to protect from salt corrosion, as well as a heat exchange system to avoid overheating - see fig.6.1.6 (Sinovel, 2013). Meanwhile, Goldwind has an environment control system embedded in the nacelle and tower to control temperature and humidity, and use various anti-corrosion methods for different components (Goldwind, 2013).

Fig.6.1.6. Diagram of Sinovel's unique nacelle seal structure and heat exchange system with salt fog protection technology.



Source: Sinovel (2013).

Certification:

In order to improve and verify the quality of their turbines, many Chinese OEMs are now seeking to certify their turbines according to accredited international standards (e.g. ISO, IEC). Turbines are therefore set to be subject to stringent quality checks to ensure reliability. This will significantly help them to enter foreign markets, which demand high levels of availability. For example, Sinovel's 6 MW turbine has been certified by TUV NORD, making it one of the first Chinese turbines to attain international certification (4coffshore, 2013).

Availability of Materials:

The availability and cost of raw materials is another factor which could affect the rate of deployment, as China progresses towards its long-term targets. Raw materials such as steel, aluminium, copper, concrete, glass fibre, carbon fibre, epoxy, and permanent magnetic materials are all used in turbine manufacture. However, the dominant material is steel, which accounts for 90% of the weight of a turbine. Steel has become a cornerstone of China's industrial growth over the past 20 years and is produced on an enormous scale. In 2009, when 13.8 GW of installed wind capacity was added in China, the amount of steel used by the wind power industry was about 1.75 Mt, only 0.38% of crude steel production in China. And despite the significant growth anticipated in China's wind industry over the coming decades, rough projections estimate that the total amount of steel needed for future wind turbine manufacturing will be 2.39 Mt in 2020, 3.04 Mt in 2030 and 6.27 Mt in 2050, comfortably within China's steel production capacity (IEA, 2011). China's steel output should therefore be sufficient to support the wind power industry for the foreseeable future.

As turbines increase in size and efforts are made to reduce the weight of the nacelle and blades, carbon fibre is expected to be used more widely. Blades, in particular, are likely to become larger and lighter through increased use of carbon fibre, in place of glass fibre. A typical 4 MW turbine with a 50m blade will require 1.2 tonnes of carbon fibre per megawatt. The IEA estimates that carbon fibre demand for Chinese turbines will be 5,300 tonnes in 2020, 10,200 tonnes in 2030, and 36,700 tonnes in 2050. However, carbon fibre production in China is significantly behind that of developed countries, who themselves are struggling to meet domestic demand. This therefore presents a significant supply gap, and China will need to focus R&D to increase the production and supply of carbon fibre if it is to use the material to meet its offshore wind targets.

The expected shift from geared to direct-drive turbines will increase the need for permanent magnetic materials in generators. These rare earth materials, such as neodymium-iron-boron (NdFeB), account for 0.75-0.8 tonnes per megawatt. In 2009, China's direct-drive wind turbines required 1,920 tonnes of NdFeB, which was only 2% of China's total NdFeB production (94,000 tonnes). While demand is set to increase to 6,800 tonnes in 2020, 9,600 tonnes in 2030, and 23,800 tonnes is 2050, China has proven reserves of rare earth materials of 90.3 Mt. The supply of NdFeB is therefore comfortably within the bounds of China's production capacity, although the price of such a rare material is likely to increase as supplies diminish over time.

6.2 Foundations

Design

There are a number of foundation designs available for offshore wind farms (fig.6.2.3) and these have been demonstrated in China. The choice of offshore foundation is determined by a series of factors:

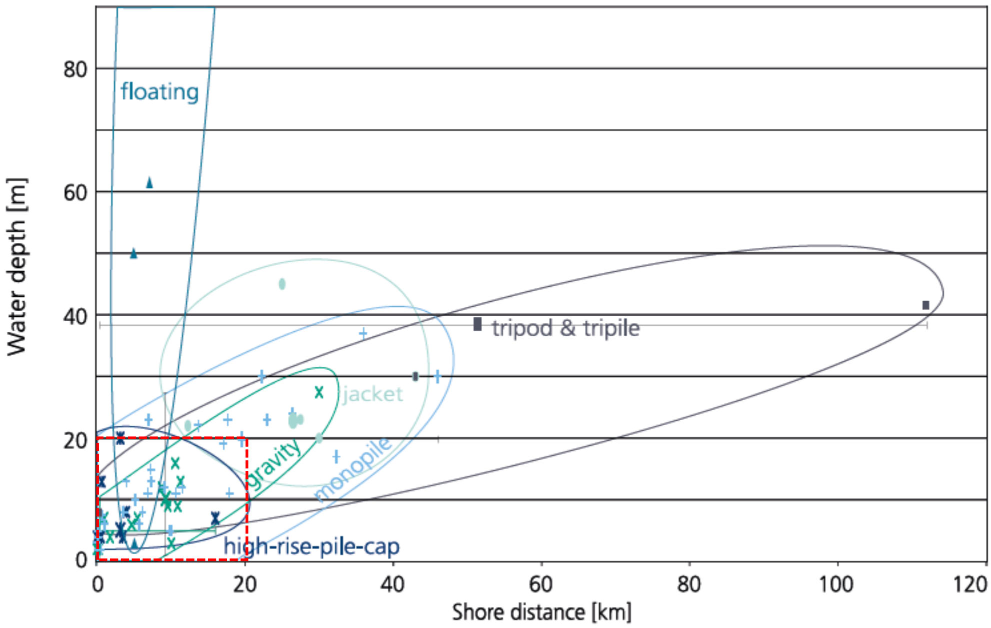
- **Seabed conditions** – China has a weak and unconsolidated upper layer of muddy and silty clay from 0-25m, with fine, silty sand underneath (fig.6.2.1). This is largely in contrast to firmer European seabed conditions. It is therefore important that foundations in China are thoroughly tested for their applicability to China's seabed conditions. Namely, it is thought that foundations could be more vulnerable to movement under the stress of turbulent met-ocean conditions.

Fig.6.2.1. Typical seabed conditions in China's coastal areas

Source: SIDRI (2013).

- **Water depth** – China expects to install the majority of wind turbines in the short-to-medium term in waters depths <12m. This is fairly shallow in comparison to Round 3 UK sites where depths are up to 60 m. For China, 10-20m water depth suggests a variety of foundation types could be used, but will unlikely need the more expensive floating foundations until wind farms move to much deeper waters (fig.6.2.2).

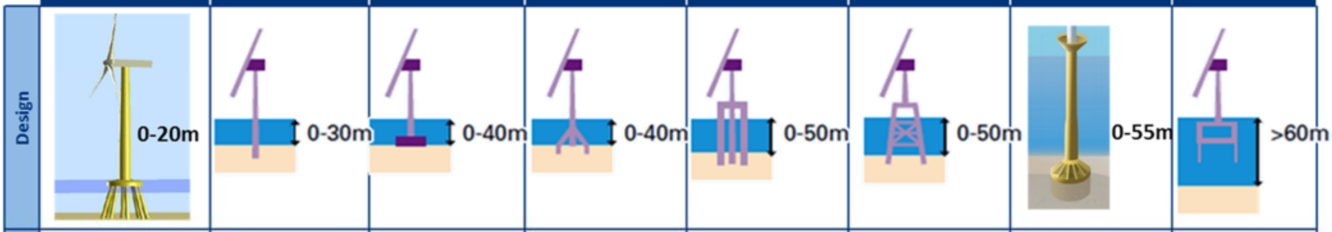
Fig.6.2.2. Applicability of different foundation types at different water depths and distances from shore (China's typical offshore wind site characteristics in red). N.B. Based on European seabed conditions.



Source: Fraunhofer (2012)

- Construction capability – China lacks significant experience installing foundations offshore. While 273 foundations and turbines have been installed to date, only 37 of these have been offshore, with the remainder in inter-tidal zones (4coffshore, 2013).
- Foundation cost – Foundations represent up to 30% of the total costs of a wind farm (Carbon Trust, 2013c). There is significant potential to reduce costs, largely through reducing the amount of steel used in the design.
- Ease of installation – Improving the rate of installation can reduce the costs of wind farm development.
- Size of wind turbine – As wind turbine size increases, foundations need to be more robust in order to handle the increased stresses and forces of supporting the extra weight.

Fig.6.2.3. Summary of the different foundations available for offshore wind turbines.

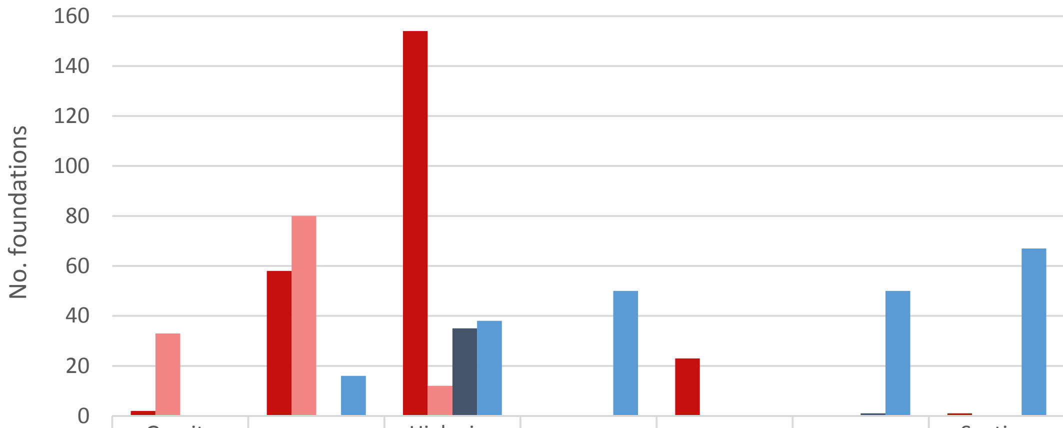


	High-rise pile cap	Monopile	Concrete gravity base	Tripod	Tri-pile	Jacket	Suction Bucket	Floating
E.g.	Donghai Bridge (CH)	Longyuan Rudong intertidal (CH)	Guodian United Power 6MW prototype (CH)	Longyuan Rudong intertidal (CH)	Bard Off-shore 1 (DE)	CNOOC Bohai Demo Turbine (CH)	DaoDa DDHI Test Project (CH)	Hywind (N)
Pros	Cap protects against maritime collisions	Simple design	Cheap No drilling	More stable than monopile	More stable than monopile	Stability Light	Less steel No drilling	Allows deep water use
Cons	Limited water depth Complex manufacturing	Diameter increases significantly with depth Drilling	Seabed preparation required	Cost More complex installation	Cost More complex installation	Cost More complex installation	Only applicable to soft seabeds	Cost
Comments	Unique to China Uncertainties on cost	Most widespread foundation type Limitations in water depth	Currently only used in shallow water	High production costs due to complex structure and weight	High production costs due to complex structure and weight	Commercially attractive >35m due to their flexibility and low weight (40-50% less steel than monopiles)	Yet to be deployed at scale	Currently at R&D stage, but could become relevant in areas with steep shores

Source: Carbon Trust (2013).

Currently in China, high-rise pile caps and monopiles are the most popular foundation choice, but a variety of foundations, including jackets, multi-piles, gravity bases, and suction bucket foundations have also been installed (fig.6.2.4). However, with most foundations having been deployed in intertidal zones (e.g. Jiangsu Rudong 150 MW intertidal project), only high-rise pile caps have been used on offshore projects (e.g. Donghai Bridge). While the intertidal zone has provided a useful testing ground for different foundation types, there is a clear need to test more foundations offshore in order to identify which are most appropriate for Chinese waters. Developers are clearly still unsure which foundations to use, with the majority of identified sites yet to announce which foundations they will use, particularly those looking to develop offshore projects.

Fig.6.2.4. Foundation types (installed and pipeline) in intertidal and offshore zones in China.*



	Gravity base	Monopile	High-rise pile cap	Tripod	Multi-pile	Jacket	Suction bucket
Intertidal (installed)	2	58	154	0	23	0	1
Intertidal (pipeline)	33	80	12	0	0	0	0
Offshore (installed)	0	0	35	0	0	1	0
Offshore (pipeline)	0	16	38	50	0	50	67

*N.B. The majority of planned sites (over 1,200 turbines) have yet to select a foundation type.

Source: www.4coffshore.com; Carbon Trust analysis.

High-rise Pile Cap

High-rise pile caps are unique to China and the first of their kind in the offshore industry. Traditionally used onshore, Chinese foundation and installation companies have been able to leverage their experience from onshore projects to install these foundations in inter-tidal and shallow offshore sites. Interviews with industry stakeholders in China also suggest that the key driver for using the high-rise pile cap is so that the cap can provide a buffer to protect the structure against maritime collisions, since the turbines are installed near to shipping navigation routes (fig.6.2.5). The multi-piles also provide stability in the soft seabed conditions.

However, high-rise pile caps tend to be deployed in calm waters close to shore, and in shallow water depths (Fraunhofer, 2012); thus they may not be applicable for sites further from shore. High-rise pile caps have been installed in Donghai Bridge, which has an average water depth of 10m. Beyond 10m, which is now a requirement for future offshore projects in China, it is unclear whether these will be suitable. Furthermore, these foundations require more complex manufacturing and have uncertain costs. So, alternative foundations may need to be explored.

Fig.6.2.5. High-rise pile cap

Source: SIDRI (2013).

Gravity

Gravity base foundations (e.g. Fuqing 5 MW prototype foundation, installed in 2012; fig.6.2.9) are also well suited to shallow water depths, concrete (low cost) and remove the necessity to drill and hammer piles into the seabed. However, they require time-intensive and difficult seabed preparation and such heavy foundations can be vulnerable to erosion and scouring in soft soils (Ibsen, 2012). Gravity base foundations are therefore also difficult to install in batch, which can limit installation rates and increase costs. Gravity base foundations are therefore generally limited to water depths <10m and are better suited to intertidal areas, rather than offshore sites.

Fig.6.2.9. Fuqing 5 MW prototype foundation (intertidal)

Source: SIDRI (2013).

Monopile

Given the fairly shallow water depths in China and the desire to scale-up deployment quickly using already proven designs, monopiles have been widely used as they are simple in structure and easy to construct, with no need for seabed preparations. There are a number of offshore monopiles in the planning process – more than any other type of foundation – which suggests that capability will be strengthened over the coming years; however, the majority of these are set to be installed in intertidal areas, not offshore. Despite installing monopiles in inter-tidal areas (fig.6.2.6), China is still new to this construction technology and has a very limited number of large piling machines (see section 6.3 on 'Installation'). However, monopiles are generally considered to be the cheapest foundation design for sites with water depth less than 30m, and it is expected that they will be installed in a number of future projects.

Fig.6.2.6. Monopile foundations installed in the 150MW Longyuan Rudong intertidal project

Source: SIDRI (2013).

Multi-pile, tripod, and jacket

Multi-pile, tripod, and jacket foundations provide more lateral support, making them well suited to China's soft seabed. Particularly as turbine size increases, this extra stability could be crucial. However, tripod foundations are generally better suited to water depths <30m, and may struggle to be cost competitive in the shallow waters of most project sites in China. Nevertheless, a variation of the typical tripod, a multi-pile jacket, has been installed in some of China's intertidal zones (e.g. 21 have been installed in Jiangsu Rudong). The multi-pile jackets installed have a similar design structure to tripods, but have five, rather than three, piles feeding in to one central column, which are also connected at the base to form a jacket structure (fig.6.2.7). This wide base gives the structure good stiffness and stability against overturning; although the main joint is complex and at risk to fatigue (LORC, 2013). Robust fabrication is therefore required to ensure longevity in its structural integrity.

Tri-pile and jacket foundations are also suited to deeper waters. The technology for these structures is already well developed from the oil and gas industry; for example, the CNOOC Bohai 1.5MW demonstration project used an existing oil platform jacket foundation (fig.6.2.8). However, the complex welded structure of such foundations, in addition to the extra steel used, increases costs. Like monopiles, multi-pile and jacket foundations also still require hammering piles into the seabed, which increases installation time and can cause environmental problems due to the level of noise it generates. It also requires very precise piling to ensure that they are positioned appropriately (LORC, 2013).

Fig.6.2.7. Multi-pile foundation installed in the Longyuan Rudong 150MW intertidal project.

Source: SIDRI (2013).

Fig.6.2.8. CNOOC Bohai 1.5MW demonstration turbine (Goldwind turbine)

Source: SIDRI (2013).

Suction Bucket

An alternative to multi-piles and jackets could be suction buckets, particularly given the soft and silty seabed conditions off China's east coast. Suction buckets sink in to the sea bed by sucking water out of the bucket skirt and creating a vacuum to hold the structure in place. Once installed, they behave much like gravity base foundations. One test suction bucket with a 2.5 MW turbine has already been installed in Jiangsu province, by DaoDa Heavy Industry Group (fig.6.2.12), and there are plans to install an array of 67 3 MW turbines with suction buckets off the coast of Hong Kong (4coffshore, 2013). The technology has yet to be deployed at scale anywhere in the world; but if more demonstration projects can verify the applicability of the technology to China's coastal conditions, bucket foundations could provide an effective solution to China's seabed conditions, as well as a means of reducing costs through using less steel.

Fig.6.2.12. DaoDa suction bucket foundation, installed in Jiangsu intertidal zone.

Source: SIDRI (2013).

Corrosion and Fatigue

The saline environment of China's coastal areas makes foundations susceptible to corrosion. Corrosion is a new problem which developers will not have experienced in the onshore industry, and is particularly common in the splash zone at the top of the foundation. However, this is not expected to be major issue for China since existing solutions, such as special coatings, already exist from the oil and gas industry (GL Garrad Hassan, 2013c).

A more critical issue for the asset integrity of foundations is the risk of fatigue, which is particularly vulnerable in foundations with many welded joints, such as the multi-piles and jackets that are likely to have a wide uptake in China. The quality of manufacture is crucial to the strength and reliability of the support structure, but with no standards or third party surveillance in place there is no means of verifying this.

Transition piece

The transition piece connects the turbine to the support structure. All foundations which are piled require a separate transition piece since they would otherwise be damaged in the hammering process. Adding the transition piece separately also provides an opportunity to level the angle of the structure, to ensure that the turbine is installed vertically, within 0.5 degrees tilt; as well as incorporating vital access facilities, such as boat landing, stairs, ladders, and working platform (LORC, 2013). However, a number of projects in China have experienced difficulty with the transition piece. In particular, manufacturers and installers have had difficulty with the transition piece 'slipping' over the pile. Furthermore, the grouting used to seal the connection has experienced failures and must be imported from Europe, increasing costs significantly.

Key Stakeholders

Foundation design in China is conducted by a handful of domestic design institutes active in the industry, who will then sub-contract the responsibility for the fabrication and installation of the foundation. For example, in China's only commercial offshore wind farm, Shanghai Investigation, Design & Research Institute (SIDRI) designed the high-rise pile cap foundations used in the Donghai Bridge project, with CCCC Third Harbour Engineering conducting the manufacture and installation. Similarly, the Rudong intertidal wind farm, developed by Longyuan Power Group, was designed by Hydrochina Huadong, with the fabrication and installation of the foundations sub-contracted to Nantong Ocean Water Conservancy Engineering Co. and Jiangsu Longyuan Zhenhua Marine Co., a joint venture between the Longyuan Power Group and maritime vessel company Shanghai Zhenhua Heavy Industries (aka "ZPMC"), which aims to provide overall construction services for Longyuan's projects, from the provision of equipment to installation and logistics (Quartz & Co., 2013).

Despite limited activity so far, there are also a number of other players involved in the market. China Offshore Oil Engineering Corporation (COOEC), a subsidiary of the developer China National Offshore Oil Company (CNOOC), hopes to leverage its experience of producing and installing offshore oil and gas structures to service the offshore wind industry, and Jiangsu DaoDa Heavy Industry (DDHI) has designed, manufactured, and installed the country's first suction bucket foundation. Indeed, DaoDa consider offshore wind to be the key pillar of its growth strategy (Quartz & Co., 2013).

A summary of the key players involved in the design, manufacture and installation of foundations is below.

Company	Design	Fabrication	Installation
Shanghai Investigation, Design & Research Institute (SIDRI)			
Hydrochina Huadong			
Guangdong Electric Power Design Institute (GEDI)			
Jiangsu Longyuan Zhenhua Marine Co.			
China Offshore Oil Engineering Corporation (COOEC)			
Nantong Ocean Water Conservancy Engineering Co. (NOWCE)			
CCCC Third Harbour Engineering			
Jiangsu DaoDa Heavy Marine Industry (DDHI)			

Source: Carbon Trust.

6.3 Installation

Foundation Installation

The method of installation is entirely dependent on the foundation design. While gravity base structures will require seabed preparation, foundations with piles (monopile, multi-pile, tripod, and jacket) will require hammer piling, and suction buckets will have their own unique method of installation.

Piled Foundation

Monopiles, multi-piles, tripods, and jackets all need piles to be hammered in to the seabed. This requires a powerful hydraulic piling hammer which can accurately maintain the vertical alignment of the foundation as it is piled in to the ground. China has struggled with a lack of capability in this area and has had to import solutions from abroad. For example, Jiangsu Longyuan Zhenhua Marine Co. purchased an 800-ton full revolving crane and S-800 hydraulic pile hammer manufactured by IHC Merwede in order to install its piled structures in Jiangsu (CLYPG, 2011). Hammer piling is also extremely noisy and is a threat to marine life. This can cause issues when attempting to pass environmental audits and gain consenting rights, particularly in areas near to marine conservation zones.

The installation of multi-piles, tripods, and jackets brings added complexity in terms of positioning the piles accurately and the sequence of installation. Furthermore, jacket structures require thorough preparation of the seabed in order to install an initial base template to drive the piles at an accurate distance from each other, before the main jacket structure can be installed (LORC, 2013). While it is expected that Chinese companies should be able to leverage experience from the oil and gas industry, there is also likely to be scope to work with European companies to develop capability in this area.

Gravity base

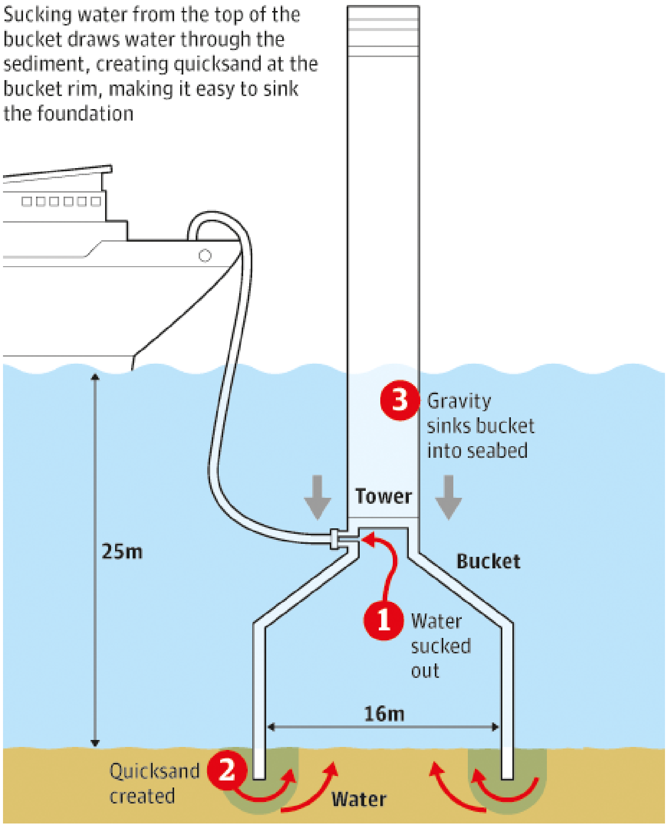
For gravity bases, accurate preparation of the seabed is necessary. Comprehensive dredging of the sea floor is followed by levelling a layer of gravel and concrete, before the structure can be lowered in to place. Typically, the foundation is transported on a barge and lifted in place using a heavy-lifting crane. The weight of the structure also tends to necessitate a fairly large vessel. However, an alternative solution to remove the need for such equipment is to use a self-floating gravity structure, which can be tugged to the site. Once installed, ballast is either pumped in to or layered around the base in order to increase its weight and improve its stability. Finally, scour protection is applied around the base in order to avoid soil erosion. While they can be floated out offshore, the greater the water depth, the greater the mass of the base, which makes transportation and installation difficult (LORC, 2013)

Suction bucket

One major advantage of suction buckets is that they do not require hammer piling. This mitigates the need to purchase a piling hammer or connect a transition piece, since it can be built directly on to the top of the support structure, secured with bolts rather than grouting (LORC, 2013). In addition, no seabed preparation is required, making installation quicker and lower cost.

The light weight of the structure means that large jack-up vessels and cranes are not required. In European demonstration projects the suction bucket has been towed out to sea with barges mounted with simple cranes to hoist the structure in to an upright position before sinking to the seabed. Once here, water is sucked out of the bucket using a mechanism on board the vessel, which creates a vacuum, forming quicksand around the rim of the skirt, which allows the bucket to sink deeper in to the sea bed (fig.6.3.1). The skirt is also fitted with nozzles which allow the bucket to be steered in to place, maintaining its vertical alignment. However, suction buckets can only be installed in soft, residual soils, much like China's sea bed condition, and is therefore not applicable to hard sea floors, where piling is necessary to hammer through the seabed.

Fig.6.3.1. Suction bucket installation.



Source: Guardian (2013)

Turbine Installation

There are two ways to install wind turbines, assemble at port or on site. This is usually determined by the installation company's vessel size and type, equipment, and capabilities, as well as the sea conditions.

> Assemble at port: China's first two commercial-scale wind farms, Donghai Bridge (fig.6.3.2) and Rudong intertidal farm, used this method. While this can reduce installation time, and thereby reduce costs, it requires large bespoke installation vessels and cranes, which will become more acute as turbine size increases. This method also requires extremely calm weather conditions, and many early European projects using this method experienced long delays as a result of this. However, in some cases, developers using this method have been able to test turbines onshore in order to repair any defects before the turbine is installed offshore (Wind Energy Update, 2011).

> Assemble offshore: The process of assembling the turbine at sea takes longer, but can be conducted with smaller vessels and cranes than those used to install pre-assembled turbine units. The degree of assembly offshore is affected by the decision to either install full rotors (with blades already attached) or single blades (blade-by-blade). However, offshore assembly is very expensive, and many developers are keen to reduce the time spent at sea.

In China, the decision to assemble on- or off-shore is likely to be heavily influenced by the availability of suitable installation vessels.

Fig.6.3.2. Installation of Sinovel 3 MW turbine at Donghai Bridge.

Source: Sinovel (2013).

Installation Vessels

Installation is the major cost for offshore wind farms in China. Vattenfall estimate vessel hire at £150,000 per day (Wind Energy Update, 2011). China lacks an established offshore wind supply chain, and is currently reliant on leveraging experience from the offshore oil and gas industry to install foundations and turbines. However, with demand increasing as more projects are consented and enter the construction phase, a number of domestic companies have developed specialised vessels for the offshore wind industry. This is also partly driven by the difficulty of importing vessels from Europe. Supply of bespoke offshore wind installation vessels is currently only just keeping pace with demand in Europe, and with demand expected to continue growing, suppliers are unlikely to free-up their vessels for use in China (Quartz & Co., 2013). Furthermore, and more critically, China's soft seabed conditions are not well-suited to the jack-up vessels which dominate the European market. Chinese wind farms must instead use more challenging floating installation vessels.

Where possible, jack-up vessels will be favoured, since jacking up the barge makes it free from any external interference from the waves, providing a solid and steady platform for the crane to operate. Floating vessels therefore require more advanced technologies to ensure stability while turbines are installed. This can include adopting a wide shape, loading the vessel with water ballast, and advanced propeller and thruster systems to allow dynamic positioning and roll stabilisation (Voith, 2013).

China certainly has the manufacturing capability to develop vessels for the industry, and has built a number of installation vessels for European customers. For example, in 2003, the world's first dedicated offshore wind turbine installation vessel, the "TIV Mayflower Resolution," was produced in China at a total cost is about $75 million (CWEA, 2013), and A2's Sea Installer vessel was built by COSCO Nantong. More recently, Seajacks placed an order with Huisman to build a 1,500 tonne Leg Encircling crane for offshore wind farm installation, which will be manufactured in Xiamen, China (Vertikal, 2013). As well as being financed and developed by foreign companies, these vessels have focussed on exports to international markets, rather than for domestic use, and are therefore not necessarily applicable to Chinese conditions. For example, the Seajacks vessel has been specifically designed to meet the demands of UK Round 3 waters.

However, in recent years a small number of Chinese companies have begun to develop vessels tailored to China's offshore market, leveraging experience from the oil and gas and shipping industries. There are currently six vessels available in China, and there are six more in production. For example, Shanghai Zhenhua Heavy Industries (a.k.a. ZPMC), part of the joint venture with Longyuan Power Group – "Jiangsu Longyuan Zhenhua Marine Co." – has developed two offshore wind installation vessels tailored to China's coastal and hydrological conditions, one installation platform and a larger installation vessel (fig.6.3.3; 6.3.4). The vessels were developed internally though ZPMC's own R&D and can operate in 30m water depth and in sediment seabed areas. As well as being able to operate as both a floating crane and jack-up, the vessel can continue to function with its bottom shell lying on the mudflat during a falling tide, making it suitable for intertidal wind farms (ZPMC, 2013). They are also equipped with a heavy-lifting crane and high-power single-pile hydraulic hammer for foundation piling, produced by IHC Merwede. Batch installation was facilitated by a barge carrying two pre-assembled turbines at a time.

Fig.6.3.3. ZPMC's smaller, offshore wind farm installation platform.

Source: www.zpmc.com

Fig.6.3.4. ZPMC's larger, offshore win farm installation vessel.

Source: www.zpmc.com

The vessels have already been successfully deployed in a handful of China's existing offshore and intertidal projects, including the Donghai Bridge offshore projects (102 MW; fig.6.3.5) and Rudong Intertidal Demonstration Wind Farm (150 MW). In the latter, the vessel was able to install, on average, one foundation pile per day and one turbine every two days (Offshore Wind Biz, 2012).

Fig.6.3.5. Installation of Sinovel 3 MW turbine using ZPMC vessel at Donghai Bridge

Source: Images from Sinovel (2013)

While shipping companies have traditionally relied on foreign vessel designs, COSCO Nantong is planning to develop its own concepts through its "ultra-large offshore wind installation platform project," which was included in the Ministry of Science and Technology's 2012 National Key New Project Plan (Offshore Wind Biz, 2012b). Meanwhile other bespoke vessels are being produced by Sany, Dalian Heavy Industry, and CSIC.

Cable Installation

Vessel Availability:

While vessel availability for foundation and turbine installation should meet demand, there is potentially a major bottleneck with regard to cable installation vessels. So far, the offshore wind industry has adapted vessels used in the oil and gas and telecommunications industries; however with demand set to increase, there is not a sufficient pipeline of bespoke vessels to reach national targets. Only two specialised vessels are currently available in the Chinese market, and there are only two companies with plans to build offshore cable installation vessels, S.B. Submarine Systems (fig.6.3.6) and Zhejiang Seahead Ship Design and Research Institute. Furthermore, with offshore sites moving to deeper waters further from shore, and the size of cables increasing, there will be increasing need for larger bespoke cable-laying vessels to serve the industry.

Fig.6.3.6. Cable installation technology aboard the CS Fu Hai cable installation vessel, designed and owned by S.B. Submarine Systems

Source: www.sbss.com

Cable Protection:

Cable damage is a major risk for offshore wind projects, with ~90% of the total number of insurance claims and ~70% of the total value of insurance claims in the industry cable related (Marsh, 2012). Approximately 70% of cable failures are due to human activity (e.g. fishing lines, anchors) (GL Garrad Hassan, 2013), so ensuring that cables are adequately protected is vital in order to mitigate these risks. Burial of the cables therefore provides the best protection. Cables are traditionally buried underground using specialised installation equipment which digs a trench in the seabed, lays the cables in place, and re-lays the bed material to provide protection.

Key Stakeholders

There are a number of players in China with capability to provide turbine and foundation installation services in the offshore wind industry. However, there is a shortage of companies supplying vessels for and undertaking cable installation, with only one player in the market, S.B. Submarine Systems.

Company	Vessel design	Vessel fabrication	Installation
ZPMC (Jiangsu Longyuan Zhenhua Marine Co.)	■	■	
COSCO Nantong Shipyard	■	■	
Dalian Heavy Industry	■	■	
China Shipbuilding Industry Corporation (CSIC)	■	■	
Sany Group	■		
Yantai Raffles Shipyard Co.		■	
Jiangsu Jiaolong Heavy Industry Group (JHI)		■	
Titan Wind (Suzhou) Co.		■	
CSSC Chengxi Shipyard Steel Construction Department		■	
Shanghai Taisheng Wind Power Equipment Co.		■	
Zhejiang Kailing Shipyard		■	
China Offshore Oil Engineering Corporation (COOEC)			■
Nantong Ocean Water Conservancy Engineering Co.			■
CCCC Third Harbour Engineering			■
Jiangsu DaoDa Heavy Marine Industry (DDHI)			■
Sinohydro Bureau 7 Co.			■
S.B. Submarine Systems (cable installation)	■		■
Zhejiang Seahead Ship Design and Research Institute (cable installation)	■		

Source: Carbon Trust.

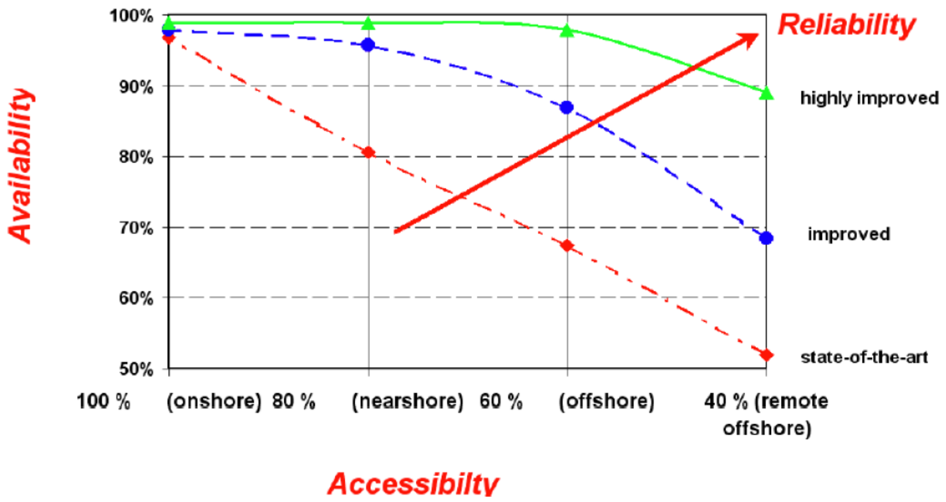
6.4 Operations & Maintenance

Operations & Maintenance (O&M) typically accounts for ~25% of total project costs (GL Garrad Hassan, 2013d), and involves ensuring that the project runs safely and cost-effectively, maximising energy output to provide commercial returns to the developer. This predominantly involves inspecting, maintaining, and repairing the wind turbines. This activity is usually initially conducted by OEMs during a specified warranty period for the turbines, which is negotiated with the developer, but typically ranges from 2-5 years. Once the warranty expires, responsibility for turbine maintenance passes on to the developer, or a third party contractor.

China has little experience of undertaking repairs offshore. While most of China's OEMs can leverage extensive experience from conducting maintenance on turbines in the onshore industry, offshore wind farms present far more complex and challenging issues. There is therefore a need to up-skill staff to be able to conduct repairs offshore, as well as developing more knowledge and capability to improve the performance of larger offshore turbines. For example, Goldwind has sought support from European consultancies to develop capability in the early years of maintaining their turbines installed in the Longyuan Rudong intertidal wind farm. Once it has developed sufficient capability, Goldwind will then help to train Longyuan staff to facilitate a smooth transition at the end of the five year warranty period (Goldwind, 2013).

The reduced level of accessibility offshore increases the necessity for highly reliable turbines (fig.6.4.1); thus the most effective way to reduce O&M costs is to improve turbine reliability. Most Chinese WTGs have been adapted from onshore models, and are new to the more complex and harsh offshore environments. Namely, they are at risk of damage from corrosion and over-heating. For example, a set of Sinovel turbines suffered damage from rusting resulting in the turbines' generators having to be replaced. Improvements to nacelle design appear to have resolved these issues, with both Sinovel and Goldwind claiming of at least 95%, but these turbines have not been installed long and a lack of data makes these claims difficult to verify.

Fig.6.4.1. Impact of availability and accessibility on turbine reliability



Source: Longyuan (2013)

Scheduled vs. Unscheduled Maintenance

Maintenance to turbines is usually classified as either scheduled/preventative or unscheduled/corrective. While scheduled repairs are proactive attempts to extend the life of components or replace known parts which are suffering wear, unscheduled maintenance involves reactive repair and replacement of component failures. The aim is therefore to limit the amount of unscheduled maintenance as much as possible, to reduce down-time for the turbine.

The most effective way of doing this is by integrating a condition monitoring system within the nacelle to identify when components need maintenance before they fail. More pre-emptive activity allows maintenance of turbines to be planned for calm weather conditions and performed in bulk, which both keeps the turbine operating and minimises the number of costly trips to conduct unscheduled repairs offshore. For example, failures during winter months, when access is difficult, can lead to significant losses if a turbine is left idle and unable to produce electricity. Using condition monitoring systems to identify component repair in advance of failure also allows time to buy replacement parts. Chinese OEMs have already developed sophisticated condition monitoring systems from their onshore turbines.

Design for Maintenance

Another means of minimising disruption to power generation and reduce the cost of O&M is to design the turbines for maintenance, using more modular designs. This allows small individual components to be repaired, rather than having to remove large features of the turbines. As well as limiting disruption, this also negates the need for large vessels and cranes to undertake repairs. This appears to have been adopted by Chinese OEMs and is particularly evident in Siemens' 6 MW turbine, which has a self-maintenance system, allowing the replacement of the gearbox, generator, and blades without external hoists (4coffshore, 2013).

O&M Strategy

The O&M strategy employed is largely dependent on the location of the wind farm. Workboats will be used in all projects, but those further from shore will also use helicopters to improve access and sites many miles from shore may have an offshore base from which to conduct repairs. However, in the case of China, where most projects are expected to be within 10-30km from shore, this is unlikely to be necessary since transit times by boat should be fairly short. The immediate focus should be on supplying enough vessels to access the wind farms.

Vessels and Transfer Systems

OEMs in China currently rent traditional vessels to conduct maintenance (e.g. Donghai Bridge project), due to the high costs of producing bespoke vessels. However, these vessels struggle to access turbines in difficult weather conditions and do not have bespoke transfer systems, which increases difficulty as well as health and safety risks. Particularly as offshore wind farms are installed further from shore, this issue is set to become more acute.

A number of Chinese companies have designed vessels for the offshore wind industry, but are waiting for demand to increase as the market takes off over the next few years. In order to meet expected demand, a large number of access vessels will be required, and DNV estimate that one bespoke O&M vessel will be required per 30 turbines installed in China. Assuming ~1,500 turbines will be required by 2015, this implies demand for 50 O&M vessels, increasing to 200 vessels by 2020. Efforts should therefore be made to increase vessel production imminently.

O&M costs

O&M costs for offshore wind are currently 1.5-2 times those onshore, largely due to a lack of experience and the cost of hiring or purchasing vessels. However, costs are expected to decrease over time as capability improves, turbines become more reliable, and the vessel market becomes more competitive. The IEA estimate that O&M costs will reach a level in line with today's onshore costs, falling from around CNY 0.15/kWh by 2020 to CNY 0.10/kWh by 2030 and 2050 (IEA, 2011).

Synthesis

China has set ambitious targets for offshore wind development which, if met, will see China become biggest offshore wind market in the world by 2020. As well as decarbonising China's energy system, offshore wind can help to meet electricity demand in China's populous and growing urban hubs along its east coast, reducing the need to transmit electricity long distances from in-land provinces. The grid along China's east coast is already well-developed, making offshore wind an attractive solution to China's growing energy needs. However, in order for China to maximise its offshore potential it will need to create the appropriate regulatory conditions to incentivise investment in the industry, as well as overcome various technical barriers (see fig.7.0.1 for a summary of the challenges identified).

Despite efforts from central government to introduce a number of progressive policies to support the development of offshore wind, the lack of a sustainable long-term incentive mechanism has stalled growth in the industry. Low FITs are probably the single biggest barrier to scaling up deployment, and a number of players will not enter the market until there is greater certainty of making profitable returns. In many parts of the supply chain, the designs and production capability is there, but suppliers are waiting for demand to increase and orders to be placed before committing the necessary funds to begin manufacturing.

While early concession projects were awarded FITs of CNY 0.62-0.74/kWh; it is expected that this needs to be closer to CNY 1.00/kWh in order for investors to make sufficient returns (~8% IRR). Although further concession projects will allow for more accurate benchmarking to define the long-term incentive mechanism, future concession rounds will need to provide more favourable returns to developers. The recent announcement to make offshore wind a priority industry over the next few years is a promising sign to suggest that more support will be given to get the fledgling industry off the ground and ramp up deployment in order to meet its near and medium term targets. Thus, while the 2015 target of 5 GW may now be out of reach, 30 GW by 2020 could still be achieved.

Another major issue to face the industry so far has been poor coordination between the various government departments, which led to delays for both the first and second concession rounds. The first concession round project have only recently started construction and the second round of concession tenders has yet to open, although it is anticipated to begin in 2014. Amendments to government legislation under the Renewable Energy Law have since provided more clarity around the discrete roles of each respective department, namely the NEA and SOA, in the consenting process, and stricter limitations regarding the location of offshore wind farms have also been imposed. While the majority of China's early offshore wind farms have been located in inter-tidal zones, sites must now be located at least 10km from shore and in waters of at least 10m depth, similar to the locations of UK Round 1 and 2 offshore wind projects.

The delay to China's early concession rounds has increased the pressure to develop wind farms quickly; however this approach brings many risks which Chinese developers should pay caution to. In particular, greater attention needs to be paid to selecting sites with the most abundant wind resource, since this has a major impact on yield and therefore the profitability of the project. Sufficient project planning time is also vitally important, particularly given the lack of experience developing offshore wind farms in China, to ensure that appropriate technologies are chosen for the site, front end engineering design (FEED) is robust, and the logistics of farm operation are efficient.

There are various technical barriers which the industry must address as it develops over the coming years. China already has a number of well-established wind turbine manufacturers from the onshore industry, and can leverage this experience to produce turbines for the offshore market. However, the larger capacity of offshore turbines and more stringent requirement for reliable performance will be challenges for OEMs.

Mastering both geared and direct-drive systems, as well as doubly-fed, permanent magnet, and superconducting generators will be key, and reducing the weight of the nacelle will also be important. China is already making progress towards developing large capacity turbines, with 5 and 6 MW turbines on the verge of being commercially available and 10 MW turbines currently in R&D, with the goal of producing a prototype by 2015. And while OEMs have traditionally been reliant on European designs, there is a growing trend to conduct more R&D in-house.

While these challenges are common across the industry at a global level, there are additional challenges for turbine manufacturers that are unique to China. Heat and humidity in the saline coastal environment off China's eastern coastline makes turbines susceptible to over-heating and corrosion, for which local solutions are already being implemented; and typhoons present a potentially major risk to asset integrity.

Unique challenges are also presented with regard to foundations. The soft unconsolidated upper layer of the seabed creates challenges for foundation design, but a variety of foundations have been demonstrated in Chinese waters. Monopiles have been installed in several projects and more innovative foundation structures, such as suction buckets, have also been tested. Given the more complex welded structures of multi-piles and jackets, fatigue becomes a risk to asset integrity, as well as corrosion; and finding solutions to problems experienced with the transition piece will also be important.

Installation techniques will be dependent on foundation choice, but there are common challenges which will apply to most designs. China currently lacks capability to produce piling hammers and there will also be a need for more installation vessels which are capable of installing foundations and turbines. China's seabed conditions make using jack-up barges difficult, which means that floating installation vessels will likely be required. China has capability to do this by leveraging its well-established shipping industry, and a series of bespoke vessels have already been produced, with more in the pipeline. However, there is potentially a major bottleneck in the supply of cable installation vessels.

Given the speed of deployment required in China, increasing the rate of installation will be necessary to maximise efficiency. Installation vessels and techniques will need to be designed appropriately to facilitate batch installation and increase the weather window in which turbines can be installed. This will also inform whether pre-assembly of turbines at port or assembly on-site offshore is most appropriate. Cable installation and burial techniques will also need to reduce the risk of damage, which can lead to costly insurance claims.

Once in operation, Chinese OEMs should be able to leverage experience from the onshore industry to conduct turbine maintenance, with condition monitoring systems used to identify impending component failures and reduce the amount of unscheduled maintenance required. Bespoke access vessels and transfer systems will be required, and although some designs have been completed, none have been produced. Production will need to increase significantly in order to service the proposed capacity of turbines in the pipeline. More generally, Chinese OEMs lack experience of operating and maintaining offshore wind farms, and will likely need support from European companies to build capability, particularly in the early years of development.

Lack of experience is a common challenge right across the supply chain. Despite ambitious plans for the near- and medium-term, the offshore wind industry is still very nascent, with only one commercial offshore wind farm in operation. Chinese developers will gain experience from early projects and will build capability significantly through learning-by-doing; but there will also be significant potential to make use of existing solutions from Europe. The water depth and distance from shore of China's planned wind farms is similar to those of the UKs Round 1 and Round 2 projects, and can benefit from bypassing some of the challenges the UK faced as a first mover in the market. However, with a number of challenges unique to China's coastal conditions, there will also be a various solutions that need to be developed locally. Finally, production throughout the supply chain will need to be scaled-up considerably beyond 2015 to an unprecedented level of growth which will see China become the global leading market for offshore wind.

Fig.7.0.1. Summary of the key challenges facing the offshore wind industry in China.

Category	Challenge	Priority
Policy	Lack of sustainable incentive mechanism (FIT)	High
	Poor government coordination around consenting	Med
Developer	Poor wind resource data	High
	Limited information on wake effects	Med
	Excessive time for wind farm development	Med
	Limited project development experience	High
Infrastructure/ Connectivity	Offshore substations	Med
	Supply of 220kV cables	Med
	Cable installation vessels	High
Turbines	Gearbox reliability	High
	Generator efficiency	High/Med
	Blade length and weight	Med/Low
	Supply of control systems and power converters	Med/Low
	Resistance to typhoons	Med
	Corrosion and over-heating	High
Foundations	Low stability in soft seabed conditions of current designs for offshore	High
	Corrosion issues	Med/Low
	Fatigue issues	High
	Transition piece connection challenges	High/Med
	High cost	High/Med
	Ease of installation	High/Med
Installation	Inadequate expertise of piling hammers	Med
	Installation vessel availability	High/Med
	Installation rate	Med
	Incidence of cable damage	High/Med
	Lack of installation experience	High/Med
Operations & Maintenance (O&M)	Quality of condition monitoring systems	Med
	Limited availability of access vessels	High
	Limited availability and design of transfer systems	High/Med
	Lack of O&M experience	High/Med

Source: Carbon Trust.

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