Prospects for global market expansion of China's wind turbine manufacturing industry

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HIGHLIGHTS

- We assess the pressure to innovate in the Chinese wind turbine market.
- Customer demand is focused more strongly on turbine cost than quality.
- Formalizing connections between users and suppliers reduce pressure to innovate.
- Chinese manufacturers cannot yet compete globally in technological quality.
- Preferential supplies of project finance may provide a vehicle for exports.

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ABSTRACT

Emerging economies are increasingly contributing to global innovation, including clean-tech innovation. The development of China's wind power sector has often been used to illustrate this point. China's domestic wind power market is the largest in the world and is largely supplied by domestic manufacturers. Competition for market share in the domestic market may pressure firms to innovate, which consecutively improves prospects for global expansion. This paper reviews developments in China's domestic wind turbine market using the Technological Innovation System framework. We analyze the pressure to innovate arising from market competition and assess the prospects for global expansion of Chinese wind turbine manufacturers. We conclude that domestic customers are not pressured or incentivized to perform with respect to power output, such that turbine manufacturers are not pressured to perform with respect to turbine efficiency or maintenance needs. Pressure to innovate is further reduced by formalizing connections between wind farm developers and turbine manufacturers. Chinese turbine manufacturers cannot yet compete with leading global brands in technological leadership. The prospects for exports are improved, however, by the preferential supply of project financing from institutional investors, such as the China Development Bank, from Chinese utilities that seek global expansion and from the manufacturers themselves.

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1. Introduction

Patterns of global economic development are undergoing change. By 2025, six major emerging economies (Brazil, China, India, Indonesia, the Republic of Korea, and the Russian Federation) will collectively account for more than half of all global growth (World Bank, 2011). Economic growth and technological prowess are known to be strongly interrelated (Abramovitz, 1986; Freeman and Soete, 1997; Kim, 1997; Nelson and Rosenberg, 1993). The changing role of emerging economies in global innovative activity is attracting

increasing academic attention (De Fuentes and Chaminade, 2012; Fu et al., 2011; Lundvall et al., 2009). A number of analysts have focused on the increasing involvement of emerging economies in global clean-tech innovation, including renewable energy technologies (Bayer et al., 2013; e.g., Berkhout et al., 2010; Binz et al., 2012; Levi et al., 2010; Pew Environment Group, 2012; Truffer, 2012).

An example of this trend is the remarkable development of China's wind power sector. In 2000, new Chinese wind power installations totaled 77.3 MW, or 2.06% of global installations (Chinese Wind Energy Association (CWEA), 2012a; Global Wind Energy Council (GWEC), 2012c). In recent years, China's new and cumulative installations of wind power have ranked first globally (Fig. 1). New installations in 2011 stood at 17.6 GW, or 43.5% of the global total (Global Wind Energy Council (GWEC), 2012c).

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China's wind turbine manufacturing has experienced similarly rapid growth. In 2000, only 2.5 MW, or 0.07% of global installations, was from any of four Chinese manufacturers (Chinese Wind Energy Association (CWEA), 2012a). By 2011, China was home to approximately 80 wind turbine manufacturers, 8 of which were among the global top 15 (Fig. 2). Compared with their foreign counterparts, however, Chinese manufacturers rely on the domestic market to a far larger extent, with very limited exports (Fig. 2).

Fig. 1. Global wind power markets.

Notes: includes the top 6 countries by cumulative installments in 2005. Sources: Chinese Wind Energy Association (CWEA) (2013), European Wind Energy Association (EWEA) (2013), Global Wind Energy Council (GWEC) (2012c), Windpower Monthly (2013b).

Fig. 2. Global wind turbine manufacturers.

Note: includes the top 15 manufacturers by 2011 market share. Collectively, these accounted for 84.5% of the 2011 global market. Sources: Chinese Wind Energy Association (CWEA) (2012c), IHS Emerging Energy Research (IHS-EER) (2012).

Table 1

12th Five-Year Plan policies and objectives for China's wind power sector.

- 12th Five-Year Plan for renewable energy' (National Energy Administration (NEA), 2012)
- By 2015: 100 GW of wind power, 5 GW of which offshore, and 190 TW h production
 - By 2020: 200 GW, 30 GW of which offshore and 390 TW h production
 - Focus on wind power bases, seven parks with 10 GW+ capacity and offshore parks
 - Improve innovative strength and international competition of the domestic industry
 - Improve the servicing industry, wind power standards and wind power use efficiency
 - Encourage more distributed wind power utilization to relieve grid stress

'Opinions on deepening technological system reform and accelerating the construction of a national innovation system' (2012–2020) (State Council of P.R. China, 2012)

- Focus on seven 'strategic emerging industries,' including wind power
- Improve 'indigenous' and independent innovative capacity; master key technologies with control over key IPR
- Formation of a number of industry giants with international influence and a batch of creative SMEs
- Integration of domestic education and science complex with the industrial chain
- Expansion of domestic and foreign markets

'12th Five-Year Plan: special plan for the development of wind power science and technology' (2012–2015) (MOST, 2012a)

- Shift from quantity to quality; reach international levels in turbine performance and reliability
- Master the design, production, and operation of 3- to 5-MW direct-drive turbines and 7-MW turbines and components
- Master the development, design and batch production of very large (10 MW+) offshore turbines

Further details concerning Chinese and leading global turbine manufacturers are provided in Appendix A.

China's achievements in wind power have been addressed in many earlier publications (e.g., Gosens and Lu, 2013; Han et al., 2009; Kang et al., 2012; Lema and Ruby, 2007; Lema and Lema, 2012; Lewis, 2007; Lewis and Wiser, 2007; Liu and Kokko, 2010; Ru et al., 2012; Wang et al., 2012; Zhang et al., 2013; Zhang and Li, 2012). Largely consistent with China's wind power policies, these papers have recognized China's late-comer status and have focused on processes of technology transfer, learning and capacity building. Policy plans for China's 12th Five-Year Plan period (2011–2015) appear to seek to end the Chinese wind power sector's dependency on foreign technology and to make China a competitor in global markets. Policy targets include more 'indigenous' innovation, turbine quality levels comparable with the global forefront, and global market expansion (see Table 1).

This paper seeks to contribute to the literature on China's wind power sector by assessing the prospects for global market expansion of China's wind turbine manufacturing. We build on the notion that the nature of competition in the domestic market is a key determinant of innovation and, by extension, prospects for global market expansion (elaborated in Section 2, theory and method). While most of the current literature on wind power in China has adopted a national scope of analysis, we focus on individual manufacturers. We assess their current innovative strength vis-à-vis global leaders, and analyze how current domestic market conditions spur further progress in innovation and prospects for competition in global markets (Section 3). We provide policy recommendations to improve these prospects in Section 4 and concluding remarks in Section 5.

2. Theory and method

The domestic market can be instrumental in developing technological leadership and can be a springboard to global markets. Empirically, the global success of wind turbine manufacturers has been found to be correlated to the size of the domestic market (Beise and Rennings, 2005; Lewis and Wiser, 2007). The top 15 manufacturers globally in 2011 (Fig. 2) were from the top 5 countries with the biggest markets and from Denmark (Fig. 1), which has historically been a lead market (Lewis and Wiser, 2007).

The home market can provide a requisite breeding ground for infant industries and can serve as an environment to test and

Table 2

Functions of a technological innovation system.

Source: based on Bergek et al. (2008), Hekkert et al. (2007).

System function	Refers to
1. Knowledge development	<ul style="list-style-type: none"> • Patenting and scientific publishing • R&D phase funding and activity
2. Knowledge diffusion	<ul style="list-style-type: none"> • Knowledge exchange in networks • Trade and co-development of IPR
3. Guidance of the search	<ul style="list-style-type: none"> • Steering development toward specific technological alternatives • Articulation of interest by leading consumers • Regulatory pressure (e.g., quotas for renewable energy)
4. Entrepreneurial activities	<ul style="list-style-type: none"> • New entrants in the market • Diversification of activities of incumbents • Amount and variety of experiments with the technology
5. Market formation	<ul style="list-style-type: none"> • Sizes and types of markets formed • Drivers of market formation (e.g., support scheme)
6. Resource mobilization	<ul style="list-style-type: none"> • Availability of capital • Availability and quality of human resources • Complementary resources
7. Creation of legitimacy	<ul style="list-style-type: none"> • Stakeholder attitudes and recognition of (societal) benefits of the technology • Rise and growth of interest groups and lobbying • Political debate in parliament and media

develop new technologies and products (Beise, 2005; Fagerberg, 1995; Porter, 1990). Competition for market share in the home market pressures manufacturers to innovate, which improves their prospects for global expansion (ibid). The relative size of the domestic market matters because it determines the possible extent of revenue and therefore the possible extent of investment in R&D (Beise, 2005).

A relatively large domestic market is, however, not a sufficient precondition for global technological leadership and export success. Porter (1990) and Fagerberg (1995) have suggested that the pressure to innovate stems from ‘advanced domestic users’ (for wind turbine manufacturers, the users would be wind farm developers). They noted that innovation may be induced by demand conditions, i.e., when domestic users sufficiently scrutinize the technological quality of different (turbine) suppliers and select their supplier accordingly (Fagerberg, 1995; Porter, 1990). Inducing turbine manufacturers to innovate does require that ‘rivalry is sufficient to respond to [demand conditions]’ (Porter, 1990: p. 72). Market entry by foreign manufacturers can also have a beneficial effect on this rivalry (Faber and Hesen, 2004; Porter, 1990; Scott, 1997), although the benefits of protectionist measures for infant industries in emerging economies are still being debated (confer e.g., Fu et al., 2011; Kim, 1993; Lewis and Wiser, 2007). Fagerberg (1995: p. 247) further extended the rivalry argument to product users, arguing that ‘users that are under continuous pressure to improve their performance are more likely [...] to demand improvements from their suppliers’. A last prerequisite for the utility of the home market as a springboard to global markets is that product qualities demanded in the domestic market should be similar to those demanded in the global market (Beise, 2005; Johanson and Vahle, 1977).

Innovation does not depend solely on interaction between users and producers, however. For instance, for clean-tech innovation in particular, government support plays an important role, e.g., in the provision of research funding, the creation of fiscal incentives for the utilization of sustainable technological alternatives, and the design of technological roadmaps. The development of a technological field can be assessed using the ‘Technological Innovation

Systems’ (TIS) framework (Bergek et al., 2008; Hekkert et al., 2007). Clean-tech innovation has received considerable attention in the TIS literature, with a particular focus on renewable energy (Markard et al., 2012). One of the attractive features of the TIS literature is the clarity of analytical scope it offers, through a list of ‘system functions,’ i.e., processes required to spur innovation (Table 2). The inclusion of basic research activities, government support measures, entrepreneurial activities and market formation suits the scope of our assessment.

The data collection for this assessment was accomplished in two separate steps. We first performed a round of desk research, reviewing journal articles, official statistics, reports from industry associations, research organizations, etc., and news items from newspapers, government and company websites. This information was used to draw up a sketch overview of China’s wind power TIS formation. We then interviewed 18 experts to correct or verify and enrich our preliminary results. The experts were 4 representatives of Chinese turbine manufacturers, 2 representatives of foreign manufacturers, 5 market analysts, 5 academics and 2 government officials.

3. China’s wind turbine sector: Market mechanisms, innovation and export market prospects

In Sections 3.1–3.7, we assess the TIS surrounding China’s wind turbine manufacturers, structured according to TIS functions (Table 2).

3.1. Knowledge development

The development of new knowledge is central to the functioning of innovation systems (Hekkert et al., 2007). We can use patenting activity to assess innovativeness in a certain technological field or country (Bergek et al., 2008). On the national level, Chinese activity in renewable power technologies has risen sharply in recent years (Bayer et al., 2013). In 2011, global wind power patent applications by applicants from China totaled 2600, compared to 3044 for EU-15 applicants and 1234 for US applicants

Fig. 3. Patent applications by wind turbine manufacturers (totals for 2010–2012).

Notes: For an explanation of Tiers, see Appendix A. Patent applications for IPC Class F03D (Wind motors) plus all subclasses. Data for patents registered abroad from esp@cenet (European Patent Office (EPO), 2012); data for patents registered in China from State Intellectual Property Office (SIPO) (2012); data for China includes invention patents only. Patent numbers for Suzlon Grp. include those from Suzlon and Repower; numbers for Enercon include grants registered to Aloys Wobben; numbers for Goldwind includes patent applications to subsidiary Vensys, numbers for XEMC includes applications by subsidiary Darwind. 'Others (avg.)' includes 49 more firms.

(analysis of online databases from European Patent Office (EPO) (2012), State Intellectual Property Office (SIPO) (2012)).

The Chinese patent numbers may be inflated, however, because China's patent office (SIPO) has three different types of patents (invention, utility model and design patents), with only the first of the three being comparable in its rigor with respect to novelty assessment. Between 2010 and 2012, 52% of all wind patents¹ registered at SIPO were invention patents. China recently amended its patent law to require absolute global novelty (as opposed to being required only for those not yet registered in China). This amendment only went into effect for new applications in early 2010 (State Council of P.R. China, 2010). Furthermore, patenting costs are relatively low in China, compared to those in the EU or the US (Roland Berger Market Research, 2004; Sayre, 2010). Lastly, a number of interviewees argued that Chinese patent numbers are inflated because political goals for innovation include grant numbers as evaluation criteria for personnel in both government and private research institutes. These interviewees argued that a relatively low share of patents granted would actually be utilized in commercial applications. This last observation is supported by the number of patent applications by Chinese wind turbine manufacturers, which is far less than the numbers of applications by their global counterparts (Fig. 3).

Conversely, a number of leading global turbine manufacturers have utilized patent portfolios to ensure thorough protection from cross-filing and to induce competitors to license from them (Totaro and Associates, 2011; UNEP/ICTSD/EPO, 2010). Application numbers may further be inflated by filing in multiple countries. For instance, between 2010 and 2012, Vestas, Siemens and GE filed 192, 388 and 197 applications, respectively, with State Intellectual Property Office (SIPO) (2012). These applications were previously or simultaneously filed with other patent offices. Lastly, Chinese manufacturers have often used foreign technology licenses, which likely include restrictions on patentability (more in Section 3.2).

Among Chinese manufacturers, patent activity largely corresponds to sales volume (see Appendix A for details). Sany and Envision are the only firms that really stand out. Sany is China's largest heavy machinery and power generation equipment manufacturing

conglomerate. As such, it has plenty of experience in related engineering fields and plenty of resources to spend on R&D activity. Envision has, unlike most manufacturers, started operations based on an independently developed turbine design. It has R&D centers in Denmark, China, Japan and the US, as well as collaboration centers at a number of Chinese universities. Both Sany and Envision are recent market entrants, however, and neither has been able to benefit much from recent market growth. The Institute of Wind Energy at the Shenyang University of Technology (SUT) is considered one of China's knowledge suppliers (see also Section 3.2), but the Institute applied for only 8 (invention) patents between 2010 and 2012.

State support for basic R&D is arranged via the creation of 'State Key Laboratories' and grants for government research programs. The establishment of a State Key Laboratory ensures state funding for an undetermined period of time, subject to annual evaluation. Some Key Laboratories have research themes, e.g., offshore wind power. State Key Laboratories are usually established within universities or within the Chinese Academy of Sciences. In the wind power sector, State Key Laboratories have mostly been established at manufacturers' facilities, as manufacturers are expected to be better able to commercialize products than academic institutions (UNIDO, 2010). Currently, wind power related State Key Laboratories are established at Sinovel, Goldwind, United Power, XEMC and Windey, and SUT. Annually renewed research programs that include wind power are the National High-tech R&D program ('863') and the National S&T support program. Grants from the 2012 '863' and S&T support programs were awarded to Sinovel, Goldwind, United Power and Windey (MOST, 2012b, 2012c). Although other manufacturers will receive R&D funding from provincial or local level governments, state support is directed nearly entirely toward the national leaders in the field.

3.2. Knowledge diffusion

The innovative capacity of manufacturers from late-comer countries can be assessed in terms of the relative dependence on foreign technology. The use of a technology license indicates relatively weak in-house capacities for turbine design, whereas cooperative and independent development indicate increasing technological competence (Lema and Lema, 2012; Lewis, 2007; Lewis and Wiser, 2007).

¹ The numbers here refer to the IPC patent class F03D (wind motors), plus subclasses.

Table 3
Technological mechanisms for turbine development of Chinese manufacturers.

	Name	License	Cooperative development	Independent development
Champions	Sinovel	2005 (Fuhrlander)	2007 (Windtec)	2009
	Goldwind	1998 (Jacobs)		2008 (Vensys)
	Dongfang	2004 (RePower)	2010 (Windtec)	
	United Power		2007 (Aerodyn)	2012
First Tier	Mingyang	2006 (Aerodyn)	2010 (Aerodyn)	
	XEMC	2006 (Zephyros)		2009 (Darwind)
	Shanghai Electric	2006 (DeWind)	2009 (Aerodyn)	2010
	China Creative			2006
	Windey	2001 (RePower)	2006 (RePower)	2009
Second Tier	CSR		2010 (Windtec)	
	CSIC Haizhuang	2006 (Frisia)	2010 (Aerodyn)	
	Envision			2008
	Yinxiang	2007 (Mitsubishi)		
	HEwind	2005 (Goldwind)	2007 (Aerodyn)	
	Energine	2005 (Acciona)		2011
	Sany		2008 (SUT)	2009
Third Tier	18 Firms			
	4 Firms		Various	
	32 Firms	Various		

Note: Most firms have more than one turbine model; data included refer to the largest-capacity model. Years indicate the first time firms developed a turbine using each respective mechanism. Names in brackets refer to the technology suppliers or partners. Goldwind and Darwind acquired Vensys and Darwind and thus integrated technology development previously performed by a foreign partner into their own operations. *Source:* China Wind Energy Equipment Association (CWEEA) (2010); company websites.

The Chinese government began encouraging international technology transfer to the domestic wind industry soon after it installed the first utility-scale wind turbines. China's earliest manufacturers were two joint ventures between foreign and domestic manufacturers, created as part of a government program (the 'Ride the Wind' program of 1997) (State Planning Commission (SPC), 1997). Between 2003 and 2009, technology transfer was promoted by making wind farm development permits conditional on a minimum percentage of locally manufactured content (NDRC, 2003, 2009a). As recently as the period between 2006 and 2011, a number of manufacturers received financial assistance from the Global Environment Fund and the NDRC to develop multi-MW wind turbines, in cooperation with foreign technology partners (under the China 'Renewable Energy Scale-up Program'; CRES, 2012). (For a more elaborate discussion of technology transfer efforts in the Chinese wind sector see, e.g., Gosens and Lu (2013), Lema and Lema (2012), Lewis (2012), Ru et al. (2012). The current policy focus is on domestic development and control over key technology (see Table 1).

On a global level, Chinese manufacturers have entered the industry relatively late. Goldwind, Windey and Dongfang were the only currently active Chinese manufacturers that were engaged in wind turbine manufacturing before 2005.

Virtually without exception, Chinese wind turbine manufacturers started operations with a licensing deal or partnership with an experienced foreign turbine designer. The evolution of the mechanisms used for turbine design by Chinese manufacturers is presented in Table 3. Many Chinese manufacturers, particularly the 'Champions'² and 'First Tier'² firms, have recently started to develop turbines independently. Although quite a few 'Third Tier' firms claim that they are engaged in independent development of wind turbine designs, our interviewees were skeptical of these claims. They argued that most of these firms assemble rather than manufacture turbines. The interviewees considered claimed independent designs to mostly be guides to assembling components

sourced from suppliers. This view is consistent with the near-total absence of patent applications by Third Tier firms.

There are also a number of manufacturers that use licenses from domestic suppliers, particularly from the Wind Energy Technology Institute of SUT. At least 17 Third Tier firms work on the basis of a technology license from SUT (China Wind Energy Equipment Association (CWEEA), 2010). Only three firms (Sany, New United and Sharpower), however, have managed to put designs into production (Chinese Wind Energy Association (CWEA), 2012a; China Wind Energy Equipment Association (CWEEA), 2010). China Creative is a spin-off firm of SUT. HEwinds' company website states it manufactures its 600-kW and 750-kW under a license from Goldwind. An engineer at SUT who was interviewed for this research indicated that SUT had no license arrangements with any foreign customers nor any current expectations of such arrangements. As far as we are aware, no Chinese manufacturer has managed to license its technology to a foreign partner.

3.3. Guidance of the search

Globally, two technological developments are being pursued. First, there is a long-standing trend toward turbine capacity increases. Several-hundred-kW turbines were the state of the art in the early nineties, MW-sized turbines emerged in the late nineties, and multi-MW turbines have been available since the turn of the millennium (Ackermann and Söder, 2002). Larger turbines are more efficient (they extract more energy from the same wind resources) and have lower installation and maintenance costs (in comparison to several smaller turbines), although they are more challenging to engineer (European Wind Energy Association (EWEA) (2011b)). A second trend is that of the search for offshore turbine models. Offshore wind farms may utilize potentially better wind resources at sea and may be built closer to load centers, i.e., urban centers in coastal areas. The search for offshore models is linked with the search for unit-scale increases. High-capacity turbines are more economical in challenging installation conditions, such as offshore locations.

The global leaders in wind turbine technology all developed multi-MW turbines during the first half of last decade and are

² For explanation of the Tier system that we use to categorize manufacturers, see Appendix A.

Fig. 4. Development of turbines offered by different manufacturers.

Notes: Indicates the largest-capacity turbine in each phase of development. 'Mass production' means at least 50 MW of that model installed by the end of 2011; years in each column indicate when the model in mass production was first installed; sources: company websites (Chinese Wind Energy Association (CWEA), 2012a; China Wind Energy Equipment Association (CWEEA), 2010).

working on further scale increases, especially for the offshore market segment (Fig. 4). Chinese manufacturers have long trailed this development but are catching up fast. By the end of 2008, only one Chinese manufacturer (XEMC) had installed turbines larger than 1.5 MW (Chinese Wind Energy Association (CWEA), 2012a). Since then, manufacturers across the board have developed turbines approximately 3 MW, and many are developing turbines with capacities of approximately 5 MW, comparable to or larger than those manufactured by the global leaders (Fig. 4). These are all prototypes, however; some of these have units installed at test farms, while others have only recently rolled off the production line (company websites; Chinese Wind Energy Association (CWEA), 2012a). Four Chinese manufacturers have even announced that they are developing 10-MW offshore models (Fig. 4).

Our interviewees were skeptical about the market demand for machines of such large capacities in the near future, however. They mentioned three main issues:

1. Lower costs of lower-capacity turbines:

The bulk of current installations in China are turbines of approximately 1.5 MW, with only 1.9% of installations having unit capacities of 2.5 MW or more (cumulative, 2011). The average turbine size in China remains smaller than in the US and EU markets (Fig. 5). The annual reports of manufacturers indicate that orders for turbines of up to 3 MW are gaining pace, but this is not the case for their largest turbines (Table 4). Interviewees assessed the preference for coupling lower-capacity turbines with their lower cost, i.e., two 1.5-MW turbines cost less than one 3-MW turbine.

2. Skepticism about performance of very-high-capacity turbines:

The market analysts that we interviewed expressed the view that the development of 10-MW turbines stems largely from a political push to demonstrate China's technological prowess (defined in MOST (2012a)); see also Table 1). Previously, China's largest wind farm developer (Longyuan) criticized the push for an offshore wind farm with domestically manufactured 3-MW units, as a showcase for the Shanghai expo. The criticism was that Sinovel, which supplied the turbines for the project, had overestimated its technological capabilities and took too little time to develop and test the new turbine, resulting in poor operational performance (People's Daily, 2011). The combined

Fig. 5. Average turbine size, key global markets.

Notes: Turbine size of new installed capacity in that year. Sources: Chinese Wind Energy Association (CWEA) (2013), European Wind Energy Association (EWEA) (2011a, 2012c), Wisser and Bolinger (2012).

Table 4

Order backlog for key Chinese manufacturers of high-capacity turbines.

Source: company annual reports. Note that order backlogs are not necessarily firm and unconditional orders.

Manufacturer	Order backlog (nr. of turbines)						Avg. size (MW)
	1.5 MW	2 MW	2.5 MW	3 MW	5 MW	6 MW	
Sinovel	2415	0	0	422	1	0	1.72
Goldwind	2575	0	384	5	0	0	1.63
Mingyang	1136	123	0	67	0	1	1.63

effect of lower cost and lower risk associated with lower-capacity turbines is reflected in manufacturers' current order backlogs (Table 4).

3. Slow offshore developments:

Very large turbines are particularly well suited to offshore wind farms. Chinese offshore installations stood at 403 MW at the end of 2012 (Chinese Wind Energy Association (CWEA), 2013), whereas those in Europe were 4.3 GW (in mid 2012), with another 3.7 GW under construction (European Wind Energy Association (EWEA), 2012a). China's offshore wind farms use turbines from Siemens (50 MW), Sinovel (170 MW), and Goldwind (110 MW). The remainder are prototype turbines from CSIC, Shanghai Electric, United Power, XEMC, Mingyang, Sany and Envision (Chinese Wind Energy Association (CWEA), 2013).

Although China's recent 12th Five-Year Plan for renewable energy stipulates ambitious goals of 5 GW of offshore installations by 2015 and 30 GW by 2020, developments have lagged behind schedule (National Energy Administration (NEA), 2012). Although tenders in 2010 and 2011 resulted in development permits being awarded for offshore projects, discussion on the siting of offshore farms among different government agencies has seriously delayed progress (Energy Research Institute (ERI), 2012).

The relative lack of demand for Chinese-brand high-capacity and offshore turbines reduces testing opportunities, stalling their further development and the build-up of operational history.

3.4. Entrepreneurial activities

Fast growing demand for wind turbines has attracted many new entrants to the domestic manufacturing industry, growing from 6 firms in 2005 to 68 in 2010 (Fig. 6). The State Council warned of an overheating industry in State Council of P.R. China (2009). Installations in 2011 totaled 17.6 GW, while production capacity exceeded 30 GW (Chinese Wind Energy Association (CWEA), 2012b, 2013). Installations in 2012 totaled 12.96 GW (Chinese Wind Energy Association (CWEA), 2013), while production capacity climbed to 37 GW or more (BTM Consult, 2012). This growth in capacity was due in part to the sheer number of manufacturers, but the problem was exacerbated by the

Fig. 6. Date of entry of manufacturers.

Note: Source: China Wind Energy Equipment Association (CWEA) (2010), company websites).

increasingly large sizes of the wind farms being developed (more in Section 3.5). To compete for equipment tenders that come in batches of several GW simultaneously, firms need to have sufficient manufacturing capacity available. Furthermore, some local and provincial governments have introduced 'localization rates,' awarding projects to manufacturers on the precondition that they set up manufacturing capacity for local employment (Chinese Wind Energy Association (CWEA), 2012b).

The customer base for turbine manufacturers, i.e., the wind farm developers, has also changed considerably in recent years. Historically, the most important developer has been Longyuan. This state-owned enterprise (SOE) was established in 1993 with a mission to develop renewable energy. In 2002, Longyuan was incorporated as a subsidiary of Guodian, one of the so-called 'Big 5' power companies (the others being China Power Investment (CPI), Datang, Huadian and Huaneng). These are state-owned enterprises (SOE) under the control of the central government. NDRC (2007) mulled a Renewable Portfolio Standard (RPS) of 3% of non-large hydro renewables in generation capacity by 2010 and 8% by 2020 for power companies with more than 5 GW of total capacity. The 'Big 5' have since led investment in wind farm development (Fig. 7). Collectively, they operate 58% of China's wind farms (as of the end of 2011). Other SOEs, mostly utilities under central or provincial government control, operate the remaining further 32% (Fig. 7).

A recent trend in entrepreneurial activity is that of increasingly formal connections between wind farm developers and turbine manufacturers (Table 5). This trend may help reduce investment costs for wind farm developers (Accenture, 2012). However, this trend also reduces competition, as a connection with a turbine manufacturer will also make it the preferred turbine supplier. Collectively, developers with formal connections with turbine manufacturers controlled 59.5% of the turbine market (for new installations as of 2011) (Table 5).

The most relevant example is the connection between Longyuan and United Power, which are both subsidiaries of the Guodian Group. United Power was established in 2007 but was the 2nd biggest manufacturer in 2012 (Chinese Wind Energy Association (CWEA), 2013). The success of this connection has depended nearly exclusively on sales to Longyuan and Guodian (Table 5). In 2009, Longyuan started preparations for future off-shore development with a 32-MW intertidal test farm in Rudong, Jiangsu Province, installing 16 turbines from 8 different manufacturers (Envision, Goldwind, Mingyang, SANY, Sinovel,

Fig. 7. China's wind farm developers by annually installed capacity (MW).

Notes: Longyuan/Guodian, Huaneng, Datang, Huadian and CPI are the so-called 'Big 5' power companies that were created with the power sector reform of 2002. 'Manufacturer' refers to turbine manufacturers that have invested in wind farm development. Source: Chinese Wind Energy Association (CWEA) (2012a).

Table 5

Formalizing relationships between wind farm developers and turbine manufacturers.

Sources: [Chinese Wind Energy Association \(CWEA\) \(2012a\)](#) and sources mentioned in the table text.

Developer	Wind farms in operation (year end 2011)		Turbine manufacturer	Type of connection	Since
	MW	% Of dom. Market			
Longyuan	9716	15.6%	United power	Both subsidiaries of Guodian Corp.	2007
<ul style="list-style-type: none"> Longyuan became a subsidiary of Guodian in 2002 (see text in Section 3.4); United Power was established as a subsidiary of Guodian in 2007 39% of Longyuan's 2011 installations were with United Power turbines, almost three times as much as the next largest supplier 					
Guodian	3887	6.2%	United power	Full subsidiary	2007
<ul style="list-style-type: none"> Guodian relied on Longyuan for wind power development until 2007. Interviewees indicated that Guodian started to develop wind farms itself, in part because of reluctance by Longyuan to use a larger proportion of United Power turbines than it already does 76% of Guodian's cumulative installations (as of the end 2011) were with United Power turbines. 89% of United Power's cumulative sales have been to Longyuan and Guodian 					
Huaneng	7964	12.8%	Sinovel	'Good relations'	2005
<ul style="list-style-type: none"> A company spokesperson explained Sinovel's success with Huaneng as being due to 'good relations,' although no formal connections, e.g., in ownership, could be identified. A number of interviewees spoke of rumors of future formalization of connections between Sinovel and Huaneng, without indicating what form such a formalization might take, e.g., a joint venture or takeover Huaneng has purchased three times more turbines from Sinovel than from any other manufacturer and is Sinovel's largest customer. Huaneng has also been the top customer for Sinovel's 3-MW model (ibid) and is currently in negotiations concerning an offshore project using 17 units of Sinovel's 6-MW turbine (Xinhua News, 2012a) 					
Huaneng	7964	12.8%	Mingyang	Joint venture	Aug. 2012
<ul style="list-style-type: none"> The joint venture is for the development of wind farms domestically and overseas (company website) Nearly 40% of Mingyang's 2011 sales were to Huaneng 					
Datang	7937	12.7%	China creative	Majority shareholder	Aug. 2011
<ul style="list-style-type: none"> Datang has a 70% stake in China Creative (State Owned Assets Supervision and Administration Commission (SASAC), 2011) 43% of China Creative's 2011 sales were to Datang 					
Datang	7937	12.7%	XEMC	Joint venture	2006
<ul style="list-style-type: none"> XEMC's wind branch is invested in by Datang (30%) and XEMC (70%) (company website) 45% of XEMC's cumulative sales (as of the end of 2011) were to Datang 					
China Guangdong Nuclear	2911	4.7%	Mingyang	Joint Venture	Sep. 2011
<ul style="list-style-type: none"> The companies, both from Guangdong Province, established a joint venture focusing on offshore and overseas developments (company website) As of the end of 2011, China Guangdong Nuclear had not installed any turbines from Mingyang 					
Tianrun	1349	2.2%	Goldwind	Parent company	2006
<ul style="list-style-type: none"> Tianrun is a subsidiary of Goldwind and exclusively uses Goldwind turbines 					
Three Gorges Corporation	1092	1.7%	Goldwind	Shareholder	Unclear
<ul style="list-style-type: none"> The Three Gorges Corporation holds 31% of Goldwind's shares (company annual report) 68% of all Three Gorges Corp. installations are with Goldwind turbines 					
Ningxia electric	1073	1.7%	Ningxia Yinxing	Full subsidiary	2007
<ul style="list-style-type: none"> All of Yinxing's sales have been to the Ningxia Electric Group. 					
Ningxia electric	1073	1.7%	Nordex-Yinchuan	Joint venture	2006
<ul style="list-style-type: none"> Nordex-Yinchuan is a joint venture between Nordex and a subsidiary of the Ningxia Electric Group. (company website) 47% of Nordex-Yinchuan's sales have been to the Ningxia Electric Group 					
CECEP	895	1.4%	Windey	Majority shareholder	2006
<ul style="list-style-type: none"> The China Energy Conservation and Environmental Protection Group (CECEP; previously CECIC) purchased a controlling share in Windey MOFCOM (Zhejiang Province) (2006) 39% of CECEP cumulative installations (as of the end of 2011) were with Windey turbines 					

Table 5 (continued)

Developer	Wind farms in operation (year end 2011)		Turbine manufacturer	Type of connection	Since
	MW	% Of dom. Market			
State Grid	880	1.4%	State power group	Shareholder	2006
<ul style="list-style-type: none"> The State Grid is a non-controlling shareholder of the State Power Group (company website) 58% of the State Power Group's 2011 sales were to the State Grid 					
State Grid	880	1.4%	Xuji Group	Full subsidiary	Jan. 2010
<ul style="list-style-type: none"> The State Grid previously acquired full ownership of the Xuji Group All of the Xuji Group's 2011 sales were to the State Grid 					
XEMC new energy, Tianwei, Changxing, Ruihao, Tiandi, Sinovel	402	0.7%	XEMC, Tianwei, Changxing, Ruihao, Tiandi, Sinovel	Parent company or manufacturers active in wind farm development	Various
<ul style="list-style-type: none"> Sinovel announced expansion into wind farm development in April of 2013, claiming 300 MW of development permits (Windpower Monthly, 2013c) 					

Shanghai Electric and United Power) (Chinese Wind Energy Association (CWEA), 2013). It remains to be seen whether the operational performance of these different turbines will affect Long-yuan's future choice of off-shore turbine supplier or whether its connections with United Power will overrule such considerations.

It should be noted that most of these formal relationships have been formed relatively recently. Their impact on competition, i.e., to what extent developers will use exclusive suppliers, remains to be seen.

3.5. Market formation

3.5.1. Chinese and global market growth

Annual installations in China peaked at 18.9 GW in 2010 but were down to 17.6 GW in 2011 and 12.96 GW in 2012 (Chinese Wind Energy Association (CWEA), 2012b). Forecasts predict 12 to 15 GW of installations annually until 2015 and 18 to 20 GW from then until 2020 (overview of forecasts from CWEA, GWEC, CREIA and BTM, as reported in Chinese Wind Energy Association (CWEA), 2012a). The recent slowdown was largely due to stricter control over permitting by the central government. Permit authority for wind farms up to 50 MW used to be in the hands of provincial governments. Most of China's wind farms have been developed in 49.5-MW sections to avoid the slower permitting procedures of the central authorities. This has, among other things, complicated the planning of additional grid capacity and high levels of curtailment (Li et al., 2012; Zhao et al., 2012a). China introduced national feed-in tariffs (FIT) in mid-2009 and concurrently stipulated that newly planned wind farms were eligible to receive FIT premiums only after approval by the central government's NDRC (2009b). China's latest policy targets are 100 GW by 2015 and 200 GW by 2020 (National Energy Administration (NEA), 2012). China is currently the largest global market and is expected to remain so for the foreseeable future (Fig. 8).

The European and US markets make up the bulk of the remainder of the global market, but there is uncertainty concerning their forecasted growth. Throughout 2012, it remained unclear whether US financial support for wind power ('production tax credits' or PTC) would be extended. The EIA has predicted 2013 installations to slump to 1 to 2 GW as a result, down from 13.1 GW in US Energy Information Administration (EIA) (2012). In early 2013, the US Congress finally agreed to extend the PTC for 2013 but without longer-term guarantees (effects of this policy

Fig. 8. Global wind turbine installations, historical and forecast for 2015 and 2020. Notes: Sources: Global Wind Energy Council (GWEC) (2012b, 2012c); country grouping as in Global Wind Energy Council (GWEC) (2012b); 2020 forecast for China set at 200 GW, as targeted by National Energy Administration (NEA) (2012) and in line with forecasts from Chinese Wind Energy Association (CWEA) (2012b).

uncertainty are discussed in e.g., Barradale, 2010). The European market is slowing down due to record low carbon prices, which have reduced the incentive to invest in wind power (@REF). Austerity has had an effect on renewable energy support in Spain, Portugal and Italy in particular and in a number of the earlier growth markets (European Wind Energy Association (EWEA), 2012b; Global Wind Energy Council (GWEC), 2012b). India, included in 'Asia other' in Fig. 8, is another important growth market but remains behind China in scale. Other emerging markets in South America, Southeast Asia and Africa are expected to grow at a rate of approximately 5 GW annually up to 2015 (Global Wind Energy Council (GWEC), 2012b).

3.5.2. Differences between domestic and export markets

The Chinese market differs from the most important export markets in terms of three basic characteristics:

1. Lower average turbine size:
As elaborated in Section 3.3.

2. Much lower turbine prices:

Prices paid for turbines in the Chinese market have consistently been much lower than those in the countries with advanced markets (Fig. 9). Chinese manufacturers have been able to offer turbines at lower prices than their foreign competitors, even if these competitors have manufacturing plants within China (Lewis, 2012; Fig. 9), largely due to the localization of component manufacture. Historically, many components needed to be imported, but the supply chain in China is increasingly able to satisfy local demand, with the exception of the demand for highly specialized steel components used in axle and yaw bearings (Chinese Wind Energy Association (CWEA), 2012b; Han et al., 2009). Our interviewees indicated that there is a gap in quality between Chinese component manufacturers and the global leaders but that this difference is offset by a far larger price gap. Manufacturing overcapacity (see Section 3.4) has further contributed to price competition. Overcapacity, both in turbines and in component manufacture, is concentrated in the 1.5-MW class. Our interviewees further indicated that development costs have traditionally been very low, as the designs used had been acquired through licensing (see Section 3.2). Newer models are increasingly developed in house, which interviewees indicated will increase R&D expenditures and reduce cost differences between Chinese and foreign brands.

3. Far higher market share of Chinese turbine brands:

The domestic market is almost entirely claimed by domestic brands. Since approximately 2005, Chinese turbine brands have

pushed out foreign competitors (Fig. 10). The four 'National Champions' have led this trend, claiming 65.5% of the domestic market in 2010. Supply has diversified since then, in favor of First Tier firms in particular, while foreign brands have seen their market shares continue to drop. The near exclusive control of the domestic market contrasts with the very limited Chinese presence in other markets (Table 6), although a number of manufacturers are negotiating foreign projects (Chinese Wind Energy Association (CWEA), 2012a, 2012b).

3.5.3. Differences between domestic and export market demand

The preference for smaller, lower-cost, and Chinese-brand turbines in the domestic market is attributable to the following six characteristics of market demand:

1. Policy targets focused on installed capacity, not power generation:

Table 6

Overview of Chinese wind turbine exports (MW).

Manufacturer	2009	2010	2011	2012
National champions				
Goldwind	4.5	4.5	189	87.25
Sinovel	15			177
Dongfang				
United Power			9	
First Tier				
Mingyang		1.5		49.5
XEMC			5	4
Shanghai electr.	6.25			
Creative				61.2
Windey				1.5
Second Tier				
CSIC			4	
HEWind		4.5	2	
SANY			12	50
Third Tier				
New United	3	3		
A-Power		2.05		
Total	28.75	15.55	221	430.45
As % of global market (excl. China)	0.12	0.08	0.97	1.35
As % of Chinese brand sales	0.24	0.09	1.38	3.41

Notes: no exports occurred before 2008; sources Chinese Wind Energy Association (CWEA) (2012c, 2013), Global Wind Energy Council (GWEC) (2012c).

Fig. 9. Turbine prices in China and advanced country markets.

Notes: 'Advanced country markets' is the average for the US, Denmark, Germany and Spain (weighted by market size). Sources: combination of European Wind Energy Association (EWEA) (2011a), IEA Wind (2012), Lewis (2012), 2011 update from CWEA.

Fig. 10. Turbine manufacturers' share of the Chinese market.

Notes: share of annual market share. Source: Chinese Wind Energy Association (CWEA) (2012a), with 2012 update for top 20 manufacturers).

China has attempted to ensure fulfillment of national policy ambitions for renewable power with obligatory Renewable Portfolio Standards (RPS) (Table 7; see also Section 3.4). These RPSs are set in percentages of generation capacity, not power production. Effectively, an RPS can be fulfilled by the installation of a number of wind turbines, regardless of the amount of electricity they deliver to the grid. Recently, production-based quotas have been discussed (Table 7). The proposed quotas would require provincial governments to issue electric power development plans that also ensure minimum consumption levels of renewables (Fig. 11). The plan appears to be aimed at relieving grid stress by fixing imbalances in wind power production (concentrated in the north) and power consumption (concentrated in coastal provinces) (for more on grid issues, see e.g., Li et al. (2012), Zhao et al. (2012a)).

The proposal initially also included kWh-based quotas for both power and grid companies, but these have since been

abandoned (Table 7). A number of our interviewees indicated that both power and grid companies have influential lobbies and would be reluctant to accept targets that could incur high costs. This reluctance is exacerbated by the interdependency of power and grid companies in meeting such targets.

2. Rush to obtain land with prime wind resources:

Developing a wind farm requires a development permit and a lease for the land (under Chinese property law, all land belongs to the State). Leases for industrial purposes last for 50 years, but development permits typically require the developer to construct a farm within two years or lose the development rights. To safeguard their long-term renewable energy strategies, power companies are competing to secure sufficient land with prime wind resources. One interviewee referred to the phenomenon as a 'land grab.' He explained that developers were reluctant to invest in turbines with longer life spans and higher power output because such investments would reduce available funds

Table 7

China's renewable power production and consumption targets.

Renewable portfolio standard (2007)

- Power companies with more than 5 GW of generation capacity are obligated to have 3% of generation capacity from non-hydro renewables by 2010 and 8% by 2020
- Legal basis: Medium- and long-term renewable energy development plan (NDRC, 2007)

Renewable power quota (draft of 2012)

- Power production or consumption quota of non-hydro renewables for power companies, grid companies and provinces. The 2015 targets are the following
- Power companies with more than 5 GW of generation capacity should generate 6.5% of all power from renewables
- Grid companies should purchase certain minimum amounts of power from renewable sources; quotas are 15% for the Inner Mongolia Grid Company, 10% for the Shaanxi Grid Company, 5% for the State Grid, and 3.2% for the Southern Power Grid Company
- Provincial governments should ensure certain minimum amounts of consumption of renewable power within their provinces; see Fig. 11 for details.
- Legal basis: Renewable power quota regulation (draft) (CEC, 2012)

Renewable power quota (draft of 2013)

- Quota for provincial governments as in the previous draft; no longer includes quotas for power or grid companies (Hu, 2013)

Fig. 11. Provincial level renewable power consumption quota.

Notes: quota are percentages of total provincial power consumption (kWh basis); targets may be met with interprovincial power transport; targets apply to the year 2015; source: CEC (2012).

for more top-quality plots of land. The financial benefits of being able to exploit these resources for the next 50 years outweigh the downside of using shorter-lived, less productive turbines for the first 10 to 20 years.

3. Concessions and 'concentrated equipment tenders':

A portion of China's wind farm development permits are auctioned in concession tenders organized by the central government.

In five annual rounds (2003–2007), a total of 2.6 GW of permits were awarded to the developer that asked for the lowest power price premium (Global Wind Energy Council (GWEC), 2007). Individual permits were for several 100 MW. Developers, incentivized by, amongst other things, RPS obligations, were eager to obtain these rights. Competitive bidding resulted in irrationally low bids, with the price pressure subsequently transferred to turbine suppliers, who were eager to receive the large orders (Li et al., 2010; Liu and Kokko, 2010). The concession tender mechanism was abandoned with the introduction of nationally determined feed-in tariffs (FIT) of between 510 and 610 RMB/MW h in 2009 (details in Hu et al. (2013), NDRC (2009b)).

The policy push to reduce the cost of wind power development continued, however, in so-called 'concentrated equipment tenders' for China's wind bases. These bases are a total of eight regions that will develop 10+ GW of wind power each (Chinese Wind Energy Association (CWEA), 2012b). The tendering process for these bases is overseen by the central government's NDRC, with separate tenders for developers and equipment manufacturers. Developers are then obligated to use the turbines of the winning equipment tender bidder. Interviewees indicated that apart from minimal technical requirements to participate in the tender (e.g., a unit capacity of at least 1.5 MW and a minimum of 100 MW of previous installations with the turbine model offered), the only selection criterion in these tenders was the price per kilowatt. Three tenders totaling 12.6 GW were held between 2008 and 2010 (Fig. 12). The National Champions have won the bulk of the tenders, as their scale of operations made it possible for them to bid lower prices for these large orders.

With a combined capacity of 15.2 GW of the total of 75.7 GW of installations by the end of 2012, these concessions and concentrated equipment tenders will certainly have an impact on the industry. Although these mechanisms have not been used for onshore developments since 2010, offshore development permits have been awarded in concessions, and again, developers have outbid each other to unprofitable levels. The bids were 680 to 780 RMB/MW h, while installations costs at sea may be two to three times higher (IEA/ERI, 2012).

4. SOEs dominate wind farm development:

The state-owned utilities dominate wind power development (Fig. 7). These SOEs have an incentive to actively participate in

achieving policy goals, i.e., to develop wind farms but also use domestic manufacture. There is no concrete obligation for the procurement of domestic wind power equipment, but there is a clear political desire to nurture the domestic wind turbine industry (see, e.g., the policies in Table 1). SOE management teams are evaluated on the basis of their adherence to government objectives, with possible consequences for their future careers (Li et al., 2008; Xu, 2011). Furthermore, such efforts will increase the enterprises' political clout in lobbying (e.g., for power pricing policies) and permit procedures for thermal power projects, which remain their main sources of income.

5. Short operational history instills little confidence in quality claims:

The most holistic metric for comparing different turbines is their so-called 'levelized cost of electricity' (LCOE). Turbine qualities that affect the LCOE include the turbine cost, efficiency (the amount of power generated in local wind conditions), maintenance cost, foregone revenue in turbine downtime, and turbine lifetime. Of these qualities, only turbine cost can be established with certainty. This is particularly true for turbines from Chinese manufacturers, most of which have been active only since 2005 or later. Manufacturers' claims concerning expected efficiency, downtime, maintenance needs and lifetime are, therefore, relatively unsupported by operational data. This is true to a greater extent for higher-capacity and offshore models, which have only been developed very recently (see Section 3.3). Faced with a 'blind spot' in decision making, developers have tended to focus on the only certain variable, i.e., turbine cost.

6. Curtailment reduces the incentive for high-quality turbines:

The pace of wind farm development and the reluctance of power grid companies to invest in grid connections have led to long connection delays. By the end of 2011, the installed capacity was 62.4 GW (Chinese Wind Energy Association (CWEA), 2012b), but the total connected and operating capacity was only 45 GW (Shi, 2012), meaning that 28% stood idle and was not generating revenue.

Power companies have also been unable or unwilling to purchase power generated by wind farms and have complained about the intermittency of the wind power supply and the concentration of power generation in regions with relatively low power demand (for details see e.g., Yang et al. (2012b), Zhao et al. (2012b)). Surplus power supply gets curtailed, i.e., wind farms get disconnected from the grid. In 2011, curtailment of wind power reached 17% nationwide and 23% in regions with high concentrations of wind farms (Chinese Wind Energy Association (CWEA), 2012b), and the curtailment only worsened in 2012 (Table 8). The uncertainty concerning the ability to sell power that has been generated reduces the incentive to pay premium prices for turbines with very high efficiencies or low amounts of downtime.

Fig. 12. Outcome of wind base 'concentrated equipment tenders'.

Source: collected news items from China Wind Power Net (2013), Chinese Wind Energy Association (CWEA) (2012a).

3.5.4. Competitive pressure and innovation in the domestic market

The competitive pressure in China's turbine market is strongly oriented toward the price per kilowatt. The senior management of Sany has criticized China's system for equipment tenders, stating that qualities such as power output, maintenance needs and operational safety have become secondary concerns (Wu and Li, 2012). This has also slashed profit margins and resulted in neglect of R&D for product development (Wu and Li, 2012). The same line of argument was reiterated by the top management of Goldwind, Sinovel and United Power at a conference forum for turbine manufacturers (CWP 2012 Conference, 2012b). Financial data for turbine manufacturers corroborate this argument (Table 9). Note that the slowdown in global markets has had similar effects on global leaders (Table 9). The consecutive pressure on R&D budgets is also apparent in manufacturers' annual reports. Goldwind (2012) planned R&D expenses for 2011 were cut by 59% to reduce operating expenses. Similarly, Sinovel scrapped recruitment plans for 350 new employees, mostly R&D personnel (Xinhua News, 2012b).

3.6. Resource mobilization

In the domestic market, Chinese turbine manufacturers and wind farms developers have had easy access to financing as a result of government stimulus measures adopted in response to the global financial crisis. In fact, loans may have been available too easily, leading to 'blind and duplicative investment' and, consequently, manufacturing overcapacity (State Council of P.R. China, 2009). Power companies used to have plenty of capital available, but this too has changed in recent years. Coal prices have risen, while electricity prices remain fixed at low, government-

determined levels (Yang et al., 2012a). The weaker financial performance of the utilities' core businesses may now hamper wind farm investment (Global Wind Energy Council (GWEC), 2012a).

Access to financing has been more difficult in export markets. Due diligence by foreign financiers requires sufficient information on operational performance. A number of international project managers of Chinese manufacturers who we interviewed indicated that the operational history of turbines in China was not considered in the due diligence for projects in the EU or US. This was said to be true even for turbine models based on licenses from globally recognized designs (e.g., those listed in Table 3). There was also a perceived investment risk due to the lack of independent performance auditing in China. Lastly, the manufacturers' poor financial performance in recent years has further increased investment risk. Turbine sales include long warranty and maintenance contracts, and uncertainty over firm survival increases doubts concerning the fulfillment of such contract obligations (CWP 2012 Conference, 2012a).

Specific difficulties exist for Sinovel, which is being sued by AMSC, which claims that Sinovel infringed on its intellectual property rights (IPR) with respect to its control system software (AMSC, 2011). Foreign developers are wary about being included in legal disputes when using Sinovel turbines. Brazilian developer Desenvix agreed to buy Sinovel's turbines only after sufficient proof that the turbines included components and software acquired from different sources (Financial Times, 2012). Ireland-based Mainstream Renewable Power withdrew from a memorandum of understanding (MoU) with Sinovel to develop 1 GW of wind parks in Ireland as a result of the dispute (company website, Recharge News, 2012).

Foreign projects may also be co-financed by the China Development Bank (CDB), which is tasked with assisting Chinese firms' foreign expansion. The CDB has, among other things, extended credit lines of \$6 bn to Goldwind, \$5 bn to United Power/Longyuan to develop wind farms in Pakistan, and \$3 bn to the Beijing Construction Engineering Group to develop a wind farm in Argentina using Chinese turbines (Bloomberg, 2012a, company websites). The inclusion of financing at low interest rates increases the competitiveness of turbine manufacturers. This is particularly true in markets in which financing is less readily accessible, such as emerging economies in Latin America, Southeast Asia and Africa

Table 8

Wind power production and curtailment in China.

Sources: combination of CEC (2013), Shi (2012), Windpower Monthly (2013a).

	Total production (TW h)	Curtailment (TW h)	Curtailment (%)	Foregone revenue (billion RMB)
2011	72.3	12.3	16.8	6.6
2012	100.4	20	19.9	10

Table 9

Financial performance of wind turbine manufacturers, 2010–2012.

	Sales ^a (MW)			Revenue ^b (mln RMB)			Profit ^c (mln RMB)		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
Chinese firms									
Goldwind	4007	3105	2583	17,475	12,756	11,224	2799	864	207
Sinovel	4386	2939	1947	20,325	10,436	4000	3133	529	–582
Mingyang	1203	1470	804	5518	5516	2893	763	454	–189
Energine	50	50	247	607	335	808	100	11	–17
Yinxiang	154	221	32	1048	926	702	87	50	32
HEwind	166	153	110	753	571	246	131	107	18
Global leaders									
Vestas	4057	5054	6171	60,481	51,240	58,810	2709	–527	33
Gamesa	2405	2802	2119	24,157	26,630	20,310	1040	1150	179
Suzlon Grp.	2514	3116	3190	25,056	28,250	30,802	1230	495	–1512
Nordex	1032	779	909	8809	8139	8972	350	–261	–498

Notes:

^a Not all annual reports supplied sales figures in MW per reporting year; for Sinovel, Yinxiang, HEWind and Suzlon, we report that year's installations.

^b Revenue may come from turbine sales but also maintenance, operation, other services, etc.

^c Profits are earnings before interest and taxes (EBIT); data for Yinxiang and HEWind are gross profits, as their annual reports contained no further specific data by business branch. This table includes all global leaders, National Champions, and First Tier and Second Tier firms with public financial reports, with separate figures on wind power equipment (for non-pure wind power manufacturers). Sources: company annual reports.

(Bloomberg, 2012b). Argentina in particular has ambitious plans for wind power development but is having trouble obtaining foreign financing after defaulting on loans in the early 2000s (Bloomberg, 2012a). A number of our interviewees indicated, however, that CDB financing for foreign projects is subject to lengthy approval procedures and in some cases is even more difficult to acquire than local financing. The CDB is more risk averse in foreign markets, in which it has little experience with renewable energy project financing and less confidence in continued government support, than it is in the domestic market.

Turbine manufacturers can also invest themselves. Sany has invested in wind farms in the US, and Tianrun, Goldwind's subsidiary, has financed wind farms in the US and Australia (company websites). Our interviewees stated that Sinovel and Mingyang have invested in a number of smaller projects that have served as showcases to attract future customers in Eastern Europe.

Lastly, a number of Chinese utilities, including Longyuan, Huaneng, Datang, and China Guangdong Nuclear, have global expansion plans (company websites), which may improve the export prospects for the turbine manufacturers with whom they have connections (Table 5). In global markets, however, these utilities are not driven by government obligations and can be expected to emphasize individual project profitability. Both Longyuan and Datang have signed MoUs with Gamesa for foreign projects (company websites). It is unclear whether preferred supplier relationships will hold up in global expansion projects. With the bulk of global expansion projects still being negotiated, it is too soon to comment on the probable outcomes with much certainty.

3.7. Creation of legitimacy

Historically, the legitimacy of Chinese government support for wind power has stemmed from the need to meet rapidly increasing power demands while minimizing greenhouse gas (GHG) emissions and the impact on air quality (Lewis, 2008; Zhang et al., 2013). Government support has been focused on building a domestic industry to reduce manufacturing costs and create new economic activity (Lewis, 2007; Ru et al., 2012).

Support for global expansion stems from industrial rather than environmental policy. While it is accepted that domestic wind power utilization requires financial support, global expansion ought to increase industrial activity and tax revenue. This implies a stronger requirement for Chinese-brand turbines to compete in terms of qualities demanded in the respective export markets. This may differ for projects in other emerging and developing countries. One interviewee referred to CDB financing for projects in these countries as 'tied aid,' i.e., development aid conditional on the use of Chinese equipment. This aid also has a political component, with projects (planned) in Cuba and Pakistan, for example—countries with historically strong political ties to China (Lewis, 2012; Reuters, 2012).

4. Synopsis and policy recommendations

China undeniably plays an important role in global innovation in wind power, now that it ranks first in installations and manufacturing volume. It is difficult to assess Chinese turbine quality accurately because of a lack of public data on operational performance. The presidents of Sinovel and Goldwind, however, have acknowledged a "quality gap with international leaders" and even being "far behind Vestas, GE or Siemens" (CWP 2012 Conference, 2012b). Although many manufacturers have independently developed their latest turbine models, the number of patent

applications by Chinese manufacturers remains markedly low. This suggests that the technological development strength of Chinese manufacturers remains moderate in comparison with that of global leaders and also casts doubt on the newness of the technology embedded in the latest Chinese-brand turbine models.

This gap may be an inevitable result of the longer operational experience (in some cases, decades) of the global leaders. The competitive pressure in the domestic market, however, does not strongly induce quality improvements. Domestic turbine users (wind farm developers) are not pressured by policy to perform in terms of power output and are disincentivized to focus on power output by current difficulties in selling power output from wind farms. As a result, domestic market demand is more strongly orientated toward turbine cost than quality. The pressure to innovate is further reduced by the recent trend of increasing integration of developers and manufacturers. There is a clear need for policy to resolve these issues.

Policy can help incentivize turbine quality improvement by improving the outlook for (and profit from) wind power sales. The recent policy push for kW h-based obligations has been met with resistance from power and grid companies. This resistance may be reduced when current grid bottlenecks are resolved. Keys to achieving this resolution will be both national and provincial planning, including balanced development of wind farms and power line infrastructure; grid flexibility, e.g., more interwoven (provincial) grids; more transport lines between generation and load centers; more local utilization of wind power and more backup capacity in the event of low wind speeds (for more, see e.g., Li et al. (2012), Zhao et al. (2012a)). Maintaining a backup of quickly dispatchable generation capacity is costly. Hydropower can be used for this purpose at moderate cost but is scarce in the wind-rich north of China (CEPP, 2013). The cost associated with balancing the intermittency of wind power can be reduced by increasing the accuracy of wind speed forecasts (Delarue et al., 2009). China's renewable energy law has been amended to clarify responsibility for grid infrastructure investment and to raise support for additional costs associated with the grid infrastructure of remote wind farms, but it remains unclear who is responsible for ensuring sufficient backup capacity and forecasting accuracy (National People's Congress (NPC), 2009). For the latter, Chinese officials could build on the experience of India, which is currently experimenting with obligatory short-term forecasting of power output from wind farms (Bloomberg, 2013).

Policy should further ensure open competition in the turbine market. Pressure to innovate will only exist if turbine manufacturers compete on equal terms in turbine tenders. It is therefore important to regulate connections between wind farm developers and turbine manufacturers. This regulation can be accomplished by introducing percentage quotas for installations with turbines from such preferred suppliers. Policy makers may also seek to regulate bid evaluation criteria, i.e., to place more value on power production rather than simply on turbine cost. Oversight over winning bid selection should also be improved, as a number of our interviewees indicated that developers did not always strictly follow their own bid evaluation criteria in choosing suppliers. Manufacturers who were not selected chose not to litigate to maintain their good standing in future tenders from these developers.

Any policy adjustment will take a considerable amount of time before it affects innovation noticeably. Chinese wind turbine manufacturers do not yet appear to have the innovative strength to compete with global leaders in the most established export markets in the near future. The quest for foreign market share is also poorly timed, as these markets are currently experiencing a downturn as well. Emerging economy markets may be more

accepting of lower-cost, lower-quality turbines. The forecasted size of these markets is limited, however. Chinese manufacturers' cost advantage will also be reduced by the costs of transport to distant markets. Furthermore, a number of emerging economy markets have introduced local content requirements (Global Wind Energy Council (GWEC), 2013), which are likely to further erode any cost advantage that Chinese manufacturers may have over global competitors.

5. Concluding remarks

Our results support Porter's (1990) hypothesis that innovation requires strong, open market competition and customers with discerning quality demands. The lack of such market conditions in China is currently reducing Chinese manufacturers' prospects of developing technological leadership and a strong presence in export markets. In comparison with users in more advanced markets, domestic users are overly focused on turbine cost and focus little attention on turbine quality.

Cost reductions do matter; they are an integral part of technological development, as witnessed by 'learning curves' that have previously been used to gauge technological maturity. Such learning curves do not make much sense, however, if the products compared differ in technological quality.

China's domestic wind turbine market is not functioning as a springboard to global market dominance. Rather, Chinese

turbine manufacturers are faced with the difficulty of catering to the product quality demands of global market customers without having a domestic market that provides the level of revenue or the development and testing environment required to do so.

However, the turbine market is not entirely commoditized. Turbine purchases are connected to project financing, which may be obtained from the China Development Bank, Chinese utilities that seek global expansion, and turbine manufacturers themselves. This implies that Fagerberg's (1995) and Porter's (1990) assumption that technological leadership is a precondition for the development of export markets may not be entirely applicable to the current global wind turbine market.

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Appendix A. Wind turbine industry details: Global leaders and Chinese manufacturers

Name	Installations (MW) (2011)				Est.	Notes
	Global, cum.	China, cum.	China, annual	Exports (%)		
Global leaders; included in 2011 top 15						
Vestas	49,332	3565	662	97.5	1979	Danish. Global market leader since the 1980s
Gamesa	24,143	2966	362	87.0	1994	Spanish. Started operations on the basis of a design license from Vestas
GE	?	1455	408	36.7	1980	American. Predecessor Zond est. 1980. GE now active in China as a JV with Harbin Power Eq.
Suzlon Grp.	20,000	1.101	96	63.1	1995	Indian Suzlon acquired German RE-Power, which was active in China as JV RE-Power North
Siemens	13,700	86	48	97.7	1980	Germany's Siemens wind division can be traced back to Danish company Bonus, est. 1980
Enercon	28,000	0	0	48.1	1983	German. Not active in China. Not active in the US after patent litigation with GE
Nordex	7543	573	50	92.0	1985	Danish. Active in China as the JV Nordex-Yinchuan
Name	Installations (MW) (2011)				Est.	Notes
	China, cum.	China, annual	Exports			
National Champions: more than 5 GW of installations						
Sinovel	12,877	2939	None	2005	SOE, pure wind power manufacturer. Subsidiary of Dalian Heavy Industry	
Goldwind	12,680	3600	5.0%	1998	SOE, pure wind power manufacturer. Goldwind's predecessor Xinjiang Wind Energy Co., a wind farm developer, was established in 1988.	

Dongfang	6816	946	None	2004	SOE, power generation equipment and heavy industry group
United Power	5252	2847	0.3%	2007	SOE, pure wind power manufacturer. Subsidiary of Guodian, one of China's largest utilities
First Tier manufacturers: 1 to 3 GW of installations					
Mingyang	3123	1178	None	2006	Privately owned, power generation equipment group
XEMC	1801	713	0.7%	2006	SOE, power generation equipment group
Shanghai Electric	1782	708	None	2006	SOE, power generation equipment group
China Creative	1349	626	None	2006	Privately owned, pure wind power manufacturer. Spin-off from Shenyang Univ. of Technology
Windey	1098	375	None	2001	SOE, pure wind power manufacturer. Spin-off from Zhejiang Inst. of Electro-mechanics
Second Tier manufacturers: 300 MW to 1 GW of installations					
CSR Zhuzhou	1037	451	None	2008	SOE, large industrial conglomerate, core product is locomotives
CSIC Haizhuang	877	396	1.0%	2006	SOE, large industrial conglomerate, main activity is shipbuilding
Envision	747	348	None	2008	Privately owned, pure wind power manufacturer
Yinxing	473	221	None	2007	SOE, provincial utility and power generation equipment manufacturer
HEwind	405	151	1.0%	2005	SOE, large industrial conglomerate (HEAG), core product is electrical apparatus
Energin	380	49	None	2005	SOE, subsidiary of China Aerospace S&T Corporation (CASC), which previously was in a JV with Spanish Acciona. Energin produces wind turbines and other rare earth applications
Sany	323	180	6.3%	2008	SOE, manufacturer of heavy machinery
Third Tier manufacturers: less than 300 MW					
Annual additions for these firms have been 50 MW or less. This is considered very small in China, as wind farms are mostly developed in 50 MW sections, with a single equipment supplier. This group contains around 50 firms, about half of them state owned and about half private firms. The bulk of these was established 2008 or later					
• Beizhong (200 MW)	• XJ Group (192 MW)	• Tianwei (189 MW)	• New United (167 MW)	• Changxing (150 MW)	• Sharpower (80 MW)
• Huide (84 MW)	• Ruihao (45 MW)	• Jiuhe (Geoho) (20 WM)	• Guoce (GC) (14)	• Hanwei (14 MW)	• 43 others (122 MW)

Note: CSR Zhuzhou should go into Tier 1 based on total installations but is more comparable to Tier 2 manufacturers in terms of company age, number of customers and geographical spread over different provinces in China. Sources: company annual reports and websites for the global leaders; (Chinese Wind Energy Association (CWEA), 2012a, 2012c; China Wind Energy Equipment Association (CWEEA), 2010) for Chinese manufacturers.

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