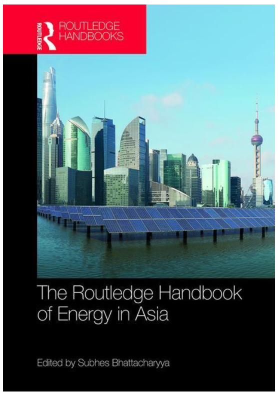

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WIND ENERGY DEVELOPMENT IN ASIA

Christopher M. Dent

Introduction

Asia's industrialisation-driven economic development has been inherently energy-intensive, its manufacturing sectors requiring huge inputs of energy resources. The ensuing environmental problems caused by this process (most notably acute urban air pollution and climate change risks) has in turn created pressures upon Asian governments to promote renewable energy as an essential element of the transition to a low carbon economy. Wind energy is the world's largest non-hydro renewables sector, and has a key role to play in that transition over forthcoming years and decades. In recent years, the centre of gravity of the wind energy sector has moved increasingly to Asia both in terms of wind energy power generation and wind turbine production. The wind energy sector can be analysed from the following general perspectives:

- *Wind turbine manufacturing*: mainly whole-assembly turbine producers (e.g. Goldwind from China, Suzlon from India), component manufacturers (e.g. gearing systems, generators) and material suppliers, such as steel for turbine towers and rotors.
- *Installed wind energy capacity*: the construction of wind farms or installation of individual wind turbines by plant developers that actually produce electricity, otherwise known as power generation.
- *Wind energy consumption*: usually through a grid system, which can be national, regional or even a community-based micro-grid. Single installation turbines are often used by farms, small communities or individual households utilising very small wind turbines.
- *Wind energy stakeholders*: including wind turbine makers and their value-chain suppliers, wind farm developers, power generation companies that initially buy wind-generated electricity that sell to the grid companies who then sell on to end consumers, policy-makers, wind energy industry associations, and communities located in or near to wind energy installations.

Wind energy resources are distributed asymmetrically within Asian countries, and across the region as a whole. For example, much of Southeast Asia is located in the 'doldrums' zone, a low-pressure area spread over equatorial latitudes where relatively calm winds exist in normal weather conditions. Consequently, it has been difficult to develop commercially viable wind energy in Singapore, Brunei and large parts of Indonesia and Malaysia. However, Asia is generally rich in wind resources and produces more wind energy generated electricity than any other region. In this chapter, we explore how Asia's wind energy sector has developed over the years, what have been the key challenges facing this development, and the prospects for Asia's wind energy in the years to come.

Wind energy: an overview

Humans have been harnessing the kinetic energy of wind in various ways across the world for centuries. Early windmill technologies in different civilisations were used to pump water and for basic agricultural processing. Vertical axis windmills are thought to have existed on the Persian–Afghan border around 200 BC, and horizontal axis windmills in the Netherlands and parts of the Mediterranean from around the 14th century onwards. Electricity-generating wind turbines were developed in Europe and the United States from the late 19th century onward, these having very-low-level kilowatt capacities. The first electricity-generating wind turbine was a 12 kilowatt (kW) device constructed at Cleveland, United States in 1888. In the early 20th century, a number of 25 kW devices were installed across Denmark. The Danish company Vestas was established in 1898 and for many years has been the world's largest wind turbine producer, although in 2015 it was displaced from the top spot for the first time by a Chinese company, Goldwind. Experimental, larger capacity wind turbines were developed around the mid-20th century, assisted by technological developments in aeroplane manufacturing (e.g. propellers, monoplane wings), with many turbines being grid-connected (Fleming and Probert 1984, Gipe 1991, Kaldellis and Zafirakis 2011).

Modern wind turbines convert the kinetic energy of moving air into mechanical and then electrical energy. The rotational energy of a moving turbine is converted into rated power by its generator, this then passing through a transformer before supplying power to an electricity grid or other system. The power output of wind turbines rises exponentially to wind speed, and areas that have constant and high wind 'densities' are naturally prime locations for developing wind farms (e.g. offshore and high altitude) to ensure the best potential and most predictable power generation. Around 3 to 4 metres per second is the threshold minimum 'cut-in' speed that modern large turbines require to produce electricity, and the maximum 'cut-out' speeds of most turbines are in the 20 to 25 metres per second range: higher speeds would cause structural and component damage. Due to wind-speed intermittencies and the non-dispatchability problem, wind energy is essentially a supplement to constant and predictable forms of energy generation.[1] However, its potential optimum share in the total energy mix will increase with grid expansion as more wind resources are harvested across larger inter-connected areas, whether within national or international spaces.

It was not until the late 1970s that an international wind energy industry began to emerge, as for other renewable energy technologies largely in response to the 1973/74 oil crisis. This development was initially concentrated in Europe and North America. However, investment and innovation in the sector remained relatively slow during the 1980s and much of the 1990s. This changed in the early 2000s due to a combination of two key factors: first, growing concerns about climate change as scientific consensus shifted increasingly towards belief of its substantive existence and significance; second, Asian governments and enterprises began to enter the market as serious industry players around this time. From the year 2000 to 2015, installed wind energy worldwide has experienced a 24-fold increase, from 18.0 GW[2] to 432.9 GW. An annual average growth rate of around 20 percent has been achieved since 2008, and the sector has added more new net installed capacity (312.0 GW) than any other energy sector during this time (Global Wind Energy Council/GWEC 2009, 2016). Wind energy generation capacity is around twice that of solar photovoltaic (PV), four times biomass generation and just under half that of hydropower globally (REN21 2016). It contributes to just over 3 percent of total worldwide power generation capacity. This is a small share but which has more than doubled in the last five years. A total of 107 countries now has installed wind energy (Windpower.net 2016).

The US initially led the way in global wind energy generation, by 1990 accounting for 79.9 percent of the global total, Europe 19.2 percent and the whole Asia and Oceania region a mere 0.9 percent. However, the positions of the US and Europe became reversed by the year 2000, the EU responsible for 73.3 percent, the US 14.2 percent while Asia now held a 9.8 percent share (Table 13.1). Thereafter, Asia began to make an increasing impact. By 2015, its share of global installed capacity had over quadrupled from its 2000 position, to 40.6 percent. In recent years, Asia has been responsible for half of global wind energy sector growth. The region's two main players have been China and India.

In 2000, China's installed capacity was just 352 MW, around the same as Britain's. From 2004 to 2009, China's capacity level doubled annually and by 2010 had overtaken the US as the world's leading installed capacity nation. By 2015 China's capacity level had reached 145.4 GW, 33.6 percent of the global total, remaining well ahead of the US (74.5 GW) and the leading European countries Germany (44.9 GW) and Spain (23.0 GW). Meanwhile, India's installed capacity level has increased from 1.3 GW in 2000 to 25.1 GW by 2015, and the Indian company Suzlon has emerged as a leading wind turbine producer. China now has five of the world's top ten turbine manufacturers – Goldwind, Guodian United Power, Mingyang, Envision and CSIC[3] (Table 13.2). Other Asian companies have become significant industry players, from Japan (Hitachi, Mitsubishi, Japan Steel Works and Komai Tekko), South Korea (Daewoo, Doosan, Hanjin, Hyundai, Samsung, STX and Unison), and Taiwan (TECO). Yet as Table 13.1 shows, Japan, South Korea and Taiwan have been relatively slow at actually installing wind turbines in their own territories. Moreover, wind energy development in Southeast Asia remains somewhat stunted: only Thailand and the Philippines have developed installed capacity of any significance although Vietnam is currently developing a number of large-scale wind farms (Windpower.net 2016). In other parts of Asia, Pakistan has plans to expand its installed capacity fivefold, from 256 MW in 2015 to 1.3 GW by 2018 based on the development of 21 projects, many of these using Chinese energy sector contractors and wind turbine equipment.[4] These will be mainly situated in the high wind potential province of Sindh, and this expansion in Pakistan's wind energy sector is due at least in part from China's broader investment in the bilateral economic and security relationship between the two nations. Pakistan is viewed as a key 'One Belt, One Road' partner to the Chinese government. Iran has meanwhile slowly built up its capacity to 118 MW, Sri Lanka to 63 MW and Mongolia to 51 MW (Table 13.1). Like in other Asian nations, a lack of capital investment and competition from other energy sectors has constrained wind energy development in these three countries.

Asia's wind energy sector is overall, then, dominated by China, its share of the region total rising from 19.8 percent in 2000, to 50.0 percent by 2008, and to 82.6 percent by 2015. Furthermore, China has driven the global growth of wind energy more than any other country. From 2008 to 2015 it added 133.2 GW of new installed capacity, equating to around 43 percent of the world total over the period. However, as we later discuss, China has faced a number of technical challenges and constraints regarding actual power generated from its burgeoning number of wind farms. Despite having installed more wind energy than any other country, and

Table 13.1 Wind energy development, Asia and global (2000–2015)

	Installed capacity (MW)										
	2000	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
China	352	2,599	5,912	12,210	25,810	44,733	62,364	75,324	91,412	114,609	145,362
India	1,267	6,270	7,850	9,587	11,807	13,066	16,084	18,421	20,150	22,465	25,088
Japan	142	1,309	1,528	1,880	2,083	2,304	2,501	2,614	2,661	2,794	3,038
South Korea	0	176	192	278	348	379	407	483	561	610	835
Taiwan	3	188	280	358	436	519	564	571	614	633	647
Pakistan	0	0	0	6	6	6	6	56	106	256	256
Thailand	0	0	0	0	0	0	8	112	223	233	233
Philippines	0	25	25	25	33	33	33	33	33	216	216
Iran	11	47	66	82	91	92	91	91	100	118	118
Sri Lanka	0	0	0	0	0	0	14	14	63	63	63
Mongolia	0	0	0	2	2	2	2	1	51	51	51
Vietnam	0	0	0	1	9	30	31	31	31	31	31
Asia total	**1,775**	**10,614**	**15,853**	**24,429**	**40,625**	**61,164**	**82,105**	**97,751**	**116,005**	**142,079**	**175,938**
% Share of world total	*9.8*	*14.3*	*16.9*	*20.2*	*25.4*	*31.1*	*34.5*	*34.6*	*36.5*	*38.4*	*40.6*
Germany	6,095	20,622	22,247	23,903	25,777	27,191	29,060	31,308	34,250	39,128	44,947
Spain	2,535	11,630	15,145	16,740	19,149	20,623	21,674	22,796	22,959	23,025	23,025

Table 13.1. (continued)

	Installed capacity (MW)										
	2000	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Britain	409	1,963	2,389	3,288	4,051	5,204	6,540	8,445	10,531	12,633	13,603
France	68	1,567	2,455	3,404	4,492	5,970	6,684	7,564	8,254	9,285	10,358
Italy	427	2,123	2,726	3,736	4,850	5,797	6,737	8,144	8,552	8,663	8,958
Sweden	241	571	831	1,067	1,560	2,163	2,907	3,745	4,470	5,425	6,025
Portugal	83	1,716	2,130	2,862	3,535	3,706	4,083	4,525	4,724	4,947	5,079
Denmark	2,417	3,136	3,125	3,160	3,465	3,749	3,871	4,162	4,772	4,881	5,063
Other EU	510	3,144	3,722	4,328	5,811	7,402	10,063	12,961	18,777	21,073	24,520
European Union	**13,225**	**48,031**	**56,517**	**64,713**	**74,919**	**84,074**	**93,947**	**106,041**	**117,289**	**129,060**	**141,578**
% share of world total	*73.3*	*64.8*	*60.2*	*53.5*	*46.9*	*42.8*	*39.5*	*37.5*	*36.9*	*34.9*	*32.7*
United States	2,564	11,575	16,823	25,237	35,159	40,180	46,919	60,007	61,091	65,877	74,471
% share of world total	*14.2*	*15.6*	*17.9*	*20.9*	*22.0*	*20.4*	*19.7*	*21.2*	*19.2*	*17.8*	*17.2*
Rest of World	490	3,948	4,799	6,613	9,161	11,310	14,817	19,067	23,989	32,689	40,896
World	**18,040**	**74,122**	**93,927**	**120,903**	**159,766**	**196,630**	**237,669**	**282,587**	**318,105**	**369,705**	**432,883**

Data source: Global Wind Energy Council/GWEC (2016, and other global annual reports), Windpower.net (2016).

Table 13.2 World's top ten wind turbine producers

2005				*2015*			
Rank	*Company*	*Country*	*Capacity (MW)*	*Rank*	*Company*	*Country*	*Capacity (MW)*
1	Vestas	Denmark	3200	1	Goldwind	China	7800
2	Enercon	Germany	2700	2	Vestas	Denmark	7300
3	Gamesa	Spain	1900	3	GE Wind	United States	5900
4	GE Wind	United States	1300	4	Siemens	Germany	3100
5	Siemens	Germany	1100	5	Gamesa	Spain	3100
6	Suzlon Group	India	900	6	Enercon	Germany	3000
7	RE Power	Germany	900	7	Guodian United Power	China	2800
8	Goldwind	China	700	8	Mingyang	China	2700
9	Nordex	Germany	500	9	Envision	China	2700
10	Ecotecnica	Spain	300	10	CSIC	China	2000

⬜	Europe	▩	China
⬛	Other Asia	⬜	North America

Data source: Bloomberg New Energy Finance/BNEF (2011, 2016).

now also the EU as a whole, ongoing technical and policy problems have meant that a large proportion of its installed capacity has been idle. Consequently, while China has more installed wind energy capacity than the United States, the better quality of the US turbines located in more optimal wind flow areas, which are more effectively connected to the grid system, has meant that by 2015 it still produced higher levels of usable wind-generated electricity than China[5] (Global Wind Energy Council/GWEC 2016).

Asia's wind energy sector in the global context

Technological and industrial perspectives

Early grid-connected wind turbines had rated power capacities of around 20–30 kW but they now range from around 0.5 MW to 8 MW, the most common of which lie in the 1.5 MW to 3 MW range. Over time, the length of turbine blades have increased from an average of around 10 metres in the 1980s, to 30–40 metres by the late 1990s, to up to around 70–80 metres by the early 2010s. By 2016 there were three firms developing 10 MW turbines: Chinese firm Shandong Swiss Electric, Norwegian company Sway and US-owned Windtec, whose machine will have rotor blades over 90 metres long and a diameter of 190 metres (Windpower.net 2016). In the Shanghai metropolitan area, just one such 10 MW turbine could potentially meet the electricity demand of around 20,000 households and in West Europe between 5,000 to 7,000 households (World Wind Energy Association/WWEA 2012). There still exists some notable differences in turbine product quality, such as power conversion efficiency ratings, and Chinese company built turbines are still generally of a lower standard than their European, Japanese and US counterparts. Meanwhile, the very small wind turbine (i.e. normally sub 0.1 MW capacity rating) industry and market has steadily grown due to deepening worldwide demand among households, communities, organisations and construction firms. By the end of 2011, there was an estimated 730,000 such units installed, China accounting for close to 70 percent of these (World Wind Energy Association/WWEA 2013). Small wind turbines are providing electricity in many remote areas of developing countries, assisted by declining costs of grid-connected inverter technology.

The average size of wind farms has also consistently increased over time, and the largest have increased from around 190 MW capacity during the early 2000s period to around 1 GW by the early 2010s, and are expected to rise to 1.5 GW in the 2016–2020 period (REN21 2014, Bloomberg New Energy Finance/BNEF 2011). In addition, there is a growing trend of community wind farm projects in Europe, North America and parts of Asia, most notably in Japan. Improvements in material technologies and component supply chain systems are extending wind turbine life-spans, which is currently around 20 to 25 years. As wind turbine technology has improved and reduced both production and operations and maintenance (O&M) costs, so wind farms in lower-resource areas have become more cost competitive, thus extending the geographic scope for wind energy development. Technological leader firms are developing cheaper and lighter composite materials, sensors related to extreme elements, and advanced blade coatings: these all mainly relate to developing more robust offshore turbines (Lee *et al.* 2009, Roland Berger 2010). Overall, wind energy is subject to high rates of techno-innovation where efficiency rating levels are improving on a constant basis (Global Wind Energy Council/GWEC 2016).

The wind energy industry has technology cluster linkages to various other high-tech sectors, such as nanotechnology, aerospace, energy storage electronics, meteorology software and marine engineering. Developed country firms still retain prominent technology advantages in wind energy, though this is likely to be challenged over time by companies from China and other emerging Asian nations (Lee *et al.* 2009). Leadership in wind energy manufacturing has shifted increasingly from Europe and North America to Asia. In 2005, only two Asian firms (Goldwind and Suzlon) were ranked in the world top ten wind turbine producers, but as Table 13.2 shows by 2015 there were five, all from China (Bloomberg New Energy Finance/BNEF 2016). By the early 2010s, the country was not only producing around half the world's wind turbines, but had also become major exporters and were improving techno-innovation capabilities (China National Renewable Energy Centre/CNREC 2013, Global Wind Energy Council/GWEC 2014, Zhou *et al.* 2012). Indian, Japanese, Taiwanese and Korean firms were also expanding their wind turbine production operations as the industry internationalised. For example, Korean conglomerate Samsung has set up operations in Britain to develop new offshore wind technology testing facilities in Europe's North Sea.[6]

The wind energy sector has matured into a mass production industry. There are now over 200 wind turbine manufacturers and over 16,000 wind farms either operational or under development worldwide. Asia has the greatest number of these in all fields. Techno-innovatory advances and intensifying competition has helped drive production and technical efficiencies.[7] In many countries, wind energy can now compete quite effectively on price against fossil fuels, and at its most efficient is on cost parity with grid-connected hydropower (Dent 2014). The wind sector may also be considered a mainstream advanced technology industry attracting fast growing research and development (R&D) funding and venture capital investment since the early 2000s. In 2004, a global total of US$14.5 billion was invested in wind energy but this had risen to an annual US$109.6 billion in 2015. Although less than solar PV this still represents higher levels of investment directed towards net additional power capacity in any fossil fuel sector or nuclear.

Offshore wind farms were first developed by Denmark in the early 1990s, and accounted for just 2.8 percent of global installed wind capacity by 2015 (Global Wind Energy Council/GWEC 2016). Although much more expensive to develop than onshore, offshore wind offers higher capacity loads due to stronger and more constant sea winds. The largest wind turbines in development are for offshore farms. They are less prone to siting conflicts (visual and noise related) and land-based transportation constraints in the wind farm construction process as offshore wind turbines are invariably manufactured in nearby seaports. Although O&M costs are normally higher than for onshore, offshore farms offer much greater scope for capturing scale economies. Offshore wind farms are situated in relatively shallow water areas (normally up to 20 metres deep) and typically up to 20 km from shore. Both distance parameters have increased over time and will continue to do so with improvements in engineering technology, thus extending offshore wind into higher energy yield zones. Many of the world's largest proposed new wind farms are offshore, and the growing involvement of oil, gas and large civil engineering firms in the offshore sub-sector has intensified competition. For Northeast Asia's densely populated economies of Japan, South Korea and Taiwan in particular, offshore wind is likely to prove a strategically important renewables option. Over 90 percent of global offshore wind energy is installed around the waters of Europe, especially in the North Sea. China's global share had steadily risen, to 8.4 percent by 2015 and is now the world's fourth largest market for offshore wind with 1 GW operational capacity (Global Wind Energy Council/GWEC 2016). However, the Chinese government failed to reach their 5 GW installed offshore wind target by the end of the 12th Five-Year Plan (FYP) period.

Scaling up the wind energy industry in Asia and globally will face certain resource challenges. For instance, motors in advanced wind turbines use a highly magnetic rare earth element, neodymium, which is almost exclusively produced at present in China, and in relatively small quantities. The larger wind turbines become, the higher the demand generated for steel, aluminium, copper and other metals and materials like carbon fibre and cement (Wiser and Bolinger 2010). The rising cost of steel was a notable cause of rising prices for wind energy between 2005 and 2009 (REN21 2012). Furthermore, continued disputes over intellectual property rights infringements between developed country companies and Chinese firms in particular may hamper future efforts at fostering techno-innovatory collaboration on wind energy development. In addition, bilateral disputes over wind turbine trade at the World Trade Organization (WTO) have soured inter-firm relations. China has again been the main target of US and EU complaints in cases taken to the WTO Dispute Settlement Mechanism, Chinese firms being accused of trade dumping practices.

Government policy and strategy perspectives

Governments at all levels have played an essential role at promoting the development of wind energy worldwide. Policies were initially aimed at financing new R&D in fledgling wind energy technologies as well as helping fund small demonstration projects. As industrial and technology capacity strengthened in the 2000s, state support progressed increasingly towards enabling utility-scale wind energy development, providing direct state support, regulatory environments and a growing range of market-based incentives for investment in new wind farms. International institutions (e.g. the International Energy Agency) and emerging renewable energy organisations (e.g. REN21) helped promote best policy practice on wind sector development where mutual learning of successful policy practice grew. In East Asia in particular, the promotion of wind energy and other renewables occurred in the broader political economic context of 'new developmentalism' (Dent 2014). This concerned the conflation of East Asia's state capacity tradition of active government involvement in guiding the economic development process with the growing influence of ecological modernisation ideas on East Asian governments. Ecological modernisation essentially concerns reconciling capitalism with sustainable development, and thus incentivising companies to invest in green industries while engaged in their usual pursuit of profit and market expansion. In a region that has long demonstrated a predilection for industrial policies, the appeal to East Asian states was that they could promote wind energy and other low carbon technologies as emerging strategic industries in addition to environmental reasons for doing so. By way of illustration, let us compare the evolution of wind energy policies in China and Japan, comparing and contrasting successes, failures and challenges faced in each country.

The Chinese government's prioritisation of wind energy over most other renewable energy sectors (the key exception being hydropower) is due in part to existing competitive advantages the country possessed in relevant engineering industries. In Japan, comparative strengths in electronics and other related industries led to the prioritisation of solar energy over wind. However, it was the Japanese government that was the first in Asia to introduce wind energy policies, deriving out of the multi-sector 1974 Sunshine Project. This, though, was more or less limited on the wind energy side to funding a handful of demonstration installations (Harborne and Hendry 2009, Ushiyama 1999). After the Sunshine Project programme review of 1990, the government sought to expand their wind energy partnerships with Japan's ten regional power companies (*Denjiren*) and emerging turbine manufacturers. It was not until the mid-1990s that the government introduced exclusive wind energy policy measures. The 1996 New Renewable Energy Target initiative set an installed capacity objective of reaching 3 GW by 2010 that subsequently the nation failed to attain (Table 13.1). In 1998 a new subsidy scheme for R&D and wind farm development was introduced, helping initially spur national installed capacity (Maruyama *et al.* 2007). By the mid-2000s, state support for wind energy R&D was terminated and funds redirected to improve grid performance and power quality (Harborne and Hendry 2009).

It took until the 1990s for China to launch its own wind energy policy, beginning with various state support measures for promoting indigenous turbine production and technology development, these though relying on joint venture arrangements with European firms such as Vestas and Gamesa. China's wind turbine manufacturers developed out of this process. In 1995, the government introduced its first power purchasing arrangement for wind energy as part of the China Electric Power Act, obliging the national grid operator to procure wind-generated electricity at prices and profit levels aimed at sustaining the growth of wind farm developers and turbine producers (Global Wind Energy Council/GWEC 2007). This was later supported in 1997 by the 'Ride the Wind' programme and parallel policy mechanisms that provided loan finance to foster indigenous industry development, install larger wind turbines in the initial four designated wind resource provinces (Inner Mongolia, Xinjiang, Zhejiang and Hebei) over the 9th and 10th FYP periods, and a local content requirement on foreign investor producers to source a 20 percent minimum of components and materials from domestic suppliers (Li 2010, Xia and Song 2009). The programme also encouraged further foreign technology transfers, German company Nordex being the first to participate in the scheme with local firm Xian Aero Engine Company (International Renewable Energy Agency/IRENA 2012). Goldwind soon followed by signing technology licensing agreements with German firms Jacobs (600 kW turbines) and REpower (750 kW) in the late 1990s, and Sinovel a 1.5 MW technology license with Furlander in 2004 (Ru *et al.* 2012).

Four key policy initiatives of the early to mid-2000s helped lay a firmer foundation for wind energy development in China. First, the 2000 National Debt Wind Power Programme offered financial support for wind farms constructed using locally made turbines and other equipment.

Second, in 2002 the government restructured the monopoly State Power Corporation into five separate power generation companies and two grid companies. Consequently, the new power generation companies became among the world's largest wind farm developers, with Guodian also establishing a wholly-owned subsidiary wind turbine producer company – Guodian United Power – currently ranked seventh in the world. However, there was now a multiplication of state actors to co-ordinate across the wind energy sector, which became exacerbated by the proliferation of private and state-owned wind turbine industry producers in subsequent years. We later discuss the implications of this and the problems arising for China's national wind energy development. Third, the 2003 Wind Power Concession Programme introduced China's first feed-in tariff (FiT) scheme[8] and targets to create up to 20 wind farms with between 100 MW and 200 MW capacity through competitive bidding, as well as a national 20 GW target by 2020. A 50 percent local content rule on turbine production was applied to the concession projects, revised upward in 2004 to 70 percent but later abolished in 2009 after China's trade partners initiated a WTO dispute case against this policy action. Fourth, the 2006 Renewable Energy Law legally obliged the two newly formed state grid companies to purchase at least 5 percent of their electricity from wind energy produced from the five new power generation companies (Global Wind Energy Council/GWEC 2007).

Whereas China's five power generation companies responded on the whole positively to the government's wind energy policies, this was not the case for their counterparts in Japan, whose ten regional *Denjiren* power companies have long proved somewhat resistant to developing this particular renewable. Up until the early 2000s, they had exercised their own 'introduction limitation quotas' on wind energy to limit their exposure to financial risk (then still relatively high generation costs) and technical risks relating mainly to its intermittent power supply. Any wind energy generated above these quota levels was competitively tendered. Collectively, *Denjiren* quotas for wind by 2003 only amounted to 330 MW, whereas wind farm developers submitted tenders totalling 2,400 MW, indicating a significant mismatch between what developers wished to supply to the market and what the power companies actually wanted to supply to the electricity grid. However, new renewable portfolio standard (RPS) legislation introduced in 2003 changed this, obligating the *Denjiren* to generate minimum quantities of electricity from renewables set by national government via the Agency for Natural Resources and Energy (Inoue and Miyazaki 2008, Maruyama *et al.* 2007). Yet the RPS targets set by the Japanese were relatively unambitious and a period of policy inertia on wind energy policy followed. In the aftermath of the global financial crisis, Japan ended its subsidies for wind energy development in 2009, and a year later the government failed to realise its 3 GW installed capacity by 2010 target for the sector.

In contrast, the Chinese government had to constantly revise its wind energy targets upward as the national market and industry continued to expand rapidly. The 12th FYP (2011–2015) set a 100 GW target for the end of the plan period, this including 70 GW from the Wind Base Programme launched in 2008 comprising mega-scale projects in Inner Mongolia, Xinjiang, Gansu, Hebei, Jilin and Jiangsu – the largest Wind Base project being at Jiuquan in Gansu province, capacity rated at 6.8 GW and over twice that of Japan's entire wind energy capacity (Global Wind Energy Council/GWEC 2014, National Development and Reform Commission/NDRC 2011). A longer term target of 150 GW grid-connected capacity by 2020 was initially set by the 12th FYP, the great majority of this (138 MW) to come from the Wind Base provinces (Kang *et al.* 2012). The 2020 target of the 12th FYP was later revised upward to 200 GW, and a special technology-oriented development plan for wind energy was introduced in 2012. This was essentially a strategic industry policy aimed at fostering capacity in high-tech large turbines. China's provincial and city governments have also played a particularly important role in developing the country's wind energy sector, exercising significant decision-making autonomy within the national policy framework (e.g. approving projects below 50 MW capacity) as well as operating their own local policies. Inner Mongolia was China's first province to devise its own distinct provincial-level policy, in 2006 issuing rules on wind farm planning, facilitating new meteorological surveys on wind resources and feasibility studies on possible new projects, as well as specifying budget resources, administrative processes and timetables for project development. Local institutionalisation of wind energy policy has been replicated in other parts of China, albeit often with a different emphasis. For example, whereas Inner Mongolia has concentrated on optimising installed capacity, Jiangsu Province has focused on promoting domestic industry production (Liu and Kokko 2010).

Most recently, the Chinese government announced it was going to gradually phase out its current FiT scheme for wind – introduced in 2009 – as the sector was becoming more commercially self-supporting and China's leadership was looking to tighten the country's fiscal position. This led to a new spurt of wind farm development applications: in 2015 China added 30.8 GW of new wind energy capacity, around half the global total. The problem is that the slowdown in the Chinese economy, and consequently in energy demand, led to much of China's expanded new wind capacity being under-utilised. Another reason for this has been the 'curtailment' problem, where wind power is available but grid operators refuse to take the electricity, instead having a preference to accept power from other sources, such as fossil fuel plants. Curtailment and other grid connectivity issues has meant that around a sixth of China's wind energy capacity has been idle in recent years. This peaked at 17 percent in 2012, falling to 8 percent in 2014 but rising again to 15 percent by 2015 (Global Wind Energy Council/GWEC 2016). The 13th FYP (2016–2020) meanwhile further revised China's 2020 wind installed target from 200 GW set under the previous plan to 250 GW, and included programmes to promote high-tech development in the sector. Despite the above noted problems, this demonstrated the Chinese government's continued commitment to expanding wind energy, which is seen as a core element of its 'energy transition' strategy.

In the early 2010s, the Japanese government again returned to promote the wind energy sector. In the wake of the Fukushima nuclear disaster, in July 2012 it extended its FiT scheme to include wind and other renewables (not just solar). While new wind FiT rates were considered generous by international comparison[9] and relative to other renewable energy sectors in the same scheme, a loophole reportedly existed that allowed the *Denjiren* to refuse wind farms connection to the grid (Ushiyama 2012). There additionally remain strict regulations on using land in forest reserves, farmland and nature reserves, and environment laws protecting against bird strikes. Previously, a 2007 building code that classified wind turbines 60 metres high or taller as buildings had effectively paralysed the Japanese wind market for around a year due to compliance to the very complicated and time-consuming planning procedures involved. Although this process was later streamlined, in October 2012 a new law required more stringent environmental impact assessments of wind farms over 10 MW capacity, in effect applying to more or less every proposed new project. These assessments were expected to take around three to five years to complete and add an anticipated extra JP¥100 million (US$1.3 million) cost to each project investment plan.[10] In July 2015, the Japanese Ministry of Economy, Trade and Industry (METI) launched its 2030 Energy Mix Plan but only set a 10 GW (1.7 percent of total power generation) future target for wind energy (Global Wind Energy Council/GWEC 2016).

In sum, the Japanese government's predominant technology-oriented approach to renewable energy generally has meant it has provided more industrial policy support to the country's wind turbine production and export rather than energy policy support to support the rapid deployment of wind energy installations within its own territory. By way of comparison, Britain – another developed, densely populated but much smaller island nation – has now over four times the wind energy installed capacity than Japan after being at quite similar capacity levels just a decade ago (Table 13.2). Offshore installation could be – like Britain – the best future option for wind energy development for Japan as well as other densely populated, advanced Asian economies like South Korea and Taiwan.

Infrastructural challenges

Almost all wind energy installations require connection with electricity grid infrastructure. This can often be a technical, financial and policy challenge. For example, most of China's best wind resources and large-scale wind farms (i.e. Wind Base plants) lie in remote areas far from the nation's main 'load centre' cities in the coastal and southern provinces – over half of the national wind capacity is located in Inner Mongolia, Gansu and northern Hebei provinces (Global Wind Energy Council/GWEC 2014). Thus, grid connectivity distances are great and the required investments in new grid infrastructure have been considerable. Zhang and Li (2012) summarise the infrastructural challenges of integrating China's now almost a thousand wind farms[11] across the country as follows: the uncoordinated development of capacity and power grids; lack of appropriate technical standards for integration; insufficient clarity over corporate responsibility for grid connection; and poor economic incentive structures for grid companies to use wind energy. Consequently, a significant level of China's installed wind energy is not actually delivering electricity to grid. Part of the problem is that investment in China's grid infrastructure has not kept pace with rapidly expanding power generation capacity generally, resulting in many power stations operating at low generation load levels. While in contrast Japan and most other Organisation for Economic Co-operation and Development nations have invested comparatively more in grid infrastructure than power generation since the late 1970s, the converse is true for China (Li *et al.* 2012). It is a predicament that applies equally to the grid's geographic coverage and transmission capacity: for example, the Northeast China grid network is based on a 500 kV system which has proved rather limited in the wind base zones (Zhao *et al.* 2012).

According to Luo *et al.* (2012), the main root of China's problem stems from the aforementioned restructuring of the energy sector in 2002 and its consequent subdivision of interests among power plant operators, electricity generation firms, grid companies, national government and local government. This created co-ordination difficulties on grid planning and construction, as well as various actors blaming others for not sufficiently investing in new grid infrastructure. Luo *et al.* (2012) also argue that a key reason for the almost uncontrollable expansion of wind farm development in China is due to the aforementioned 50 MW capacity approval rule. To evade coming under relatively stricter NDRC approval at this threshold capacity level, a large number of wind farm projects rated at 49.5 MW have emerged that only required comparatively looser local government approval, further weakening national government grip on the sector's development overall. The approval process for wind farms (especially smaller ones) has also hitherto been much quicker than for constructing new transmission lines, and wind farm developers willing to wait some months or even years for grid connectivity that has contributed to the capacity–generation gap.

A key part of the problem concerns policy incentives and strategic planning geared towards installation rather than power generation output, leading to 'excess' installed capacity problems. Zhang *et al.* (2013) contend that this approach was primarily driven by strategic industry policy motives in that setting ambitious targets on installed wind energy was conceived as an important driver for expanding China's turbine manufacturing base. Poor co-ordination between government agencies (urban, environment, industrial policy) on wind farm development was also clearly evident (Luo *et al.* 2012). Given that wind energy is a fast emerging and potentially very profitable industry in China, wind farm developers have been able to attract considerable investment. The lack of appropriate grid connectivity technical standards or codes specifically for wind farms, and poor compliance by operators where they do exist, has too meant an underuse of wind energy generated and bad management of the grid transmission system during high wind-speed periods, leading to power generation cut-outs in parts of the grid (Kang *et al.* 2012).

There have too been weak incentives for new grid infrastructure investment. In China‘s electricity generation industry, a planned market applies for base power needs and an open trade market for incremental power needs between producers and consumers. This affects how electricity is traded on an inter-provincial basis, and thus how wind energy generated in remote areas is sold to large load centres some distances away, as only incrementally produced wind energy is effectively tradable across the regions. Moreover, as there has been no national standard price formula for inter-provincial power transmissions, prices are determined by bilateral negotiations between provincial authorities, which have created significant transaction costs. By the early 2010s there was also still no mechanism to compensate grid companies for the inevitable power losses arising from long-distance transmissions, thus offering the grid companies little incentive for facilitating inter-provincial wind energy trade (Zhao *et al.* 2012).

The 12th FYP sought to address problems regarding China‘s grid infrastructure and regulatory gaps on wind energy. In 2012 the National Energy Association introduced the Wind Farm Development and Management Interim Rules and Regulation that stipulates wind farms must acquire complete approval from the authorities before commencing operation, and other measures that aim to strengthen quality control over installations. A new Safety Management of Wind Farms procedure has been brought into force, and the government is now encouraging development of wind farms closer to main load centres albeit in low wind-speed areas. Furthermore, a new grid code and 17 other technical standards have been introduced, and operators' use of low voltage ride through technology (Global Wind Energy Council/GWEC 2012). The central government also took more direct control of wind farm development within 12th FYP strategic plans, wrestling power away from local government. Investment totalling RMB3.8 trillion (US$580 billion) for 'strong and smart grid' development up to 2020 has additionally been implemented that should in time alleviate many of these grid connectivity problems (Global Wind Energy Council/GWEC 2013). However, for smart grids to perform optimally they should be allowed to operate on certain decentralisation principles and being reactive to consumer demand, which will require the Chinese power generation sector to become more open and competitive rather than staying monopolised by a few state-owned enterprises (Solidiance 2013).

Japan, South Korea and Taiwan face similar challenges to China regarding the exploitation of the nation's best wind resources, which are located in remote, sparsely populated areas far from main load centres. Around 70 percent of all three territories are mountainous, presenting certain technical and logistical challenges when developing wind farms in non-urbanised areas. A result of many wind energy developers having to build on hilly terrain has meant that installation costs are around twice the levels as the United States.[12] After the 2011 Fukushima disaster there has been growing political support for rationalising and expanding Japan's grid infrastructure to improve electricity trading among regions (Global Wind Energy Council/GWEC 2012). However, even with political backing it could take up to a decade before the nation's grid infrastructure was sufficiently extended into remote northern (Hokkaido and Tohoku) and southern (Kyushu) areas, where Japan's best wind resources are located. The government's aforementioned 2013 JP¥25.0 billion plan for new grid extension investment is perhaps the first important step in this direction.

Institutional and socio-technical perspectives

Institutional support for wind energy development at the national level across Asia has generally strengthened over time as government policy towards the sector has strengthened. A growing number of national business associations, environmental organisations, research institutes and other relevant bodies have helped promote wind energy as a part of their agendas for a low carbon energy transition. International energy and climate-related institutions such as the International Energy Agency, International Renewable Energy Agency, Inter-governmental Panel on Climate Change and United Nations Framework Convention on Climate Change (UNFCCC) have together with the Global Wind Energy Council and miscellaneous business alliances (e.g. the Breakthrough Energy Coalition) are also strongly supporting wind energy development as part of their push on renewables generally. For example, the Clean Development Mechanism programme introduced in 2005 under the auspices of the UNFCCC's Kyoto Protocol helped fund 1,517 wind energy projects in China, and 805 projects in India, and around 40 others elsewhere in Asia by September 2013 (Dent 2014).

As well as having a conducive institutional environment for promoting wind energy development, there are also important socio-technical factors to consider. Generally speaking, most wind energy installations are wind farms, these being 'utility-scale' plants for electricity generation fed into a grid system. This is in contrast to the more 'distributed' nature of solar PV where a myriad of much smaller scale roof-top installations form the sector's aggregated whole. Moreover, solar PV panels have a much lower spatial profile and visible imprint than wind turbines, which as discussed earlier have gradually become larger and taller. The siting of wind farms near inhabited areas have become a socio-politically sensitive issue in Asia and globally. In the densely populated and liberal democratic states of Japan, South Korea and Taiwan there has been strong well-organised local protests against wind farm development. Furthermore, their governments have tough planning permission regulations to help protect the already scarce publicly accessible countryside. In South Korea, it has been reported that only a quarter of wind farm proposals are approved for this reason (Global Wind Energy Council/GWEC 2012). There has, though, been evidence of local opposition to wind farm projects waning in the aftermath of the 2011 Fukushima nuclear disaster (Mizuno 2014). Future advances in small wind turbine technology aimed at integrating devices into buildings and other constructions would pose a different set of socio-technical challenges yet also make the public more direct stakeholders in the sector akin to the solar PV 'prosumer' (i.e. simultaneously producer and consumer) development over the last few decades. The small-scale application possibilities offered by renewable energy technologies generation pose the prospect of a 'new energy societies' being created in the low carbon revolution (Dent 2014).

Conclusion

Asia is the most carbon-intensive part of the planet. This is not surprising given it continues to be by far the world's most populous region or continent, and its burgeoning twin processes of industrialisation and urbanisation. Over recent years and decades, Asian societies have consumed increasing levels of energy and this trend shows little sign of abating. The challenge is, then, to promote renewable and other low carbon energy development that will not just keep pace with Asia's energy consumption growth but at an even faster pace than this, if the region is to make an effective and successful transition to decarbonised energy and economic systems. Asian countries have a huge impact on global carbon emissions and thereby climate change, and most are also highly susceptible to climate change risks. Wind energy is now a mainstream energy sector that has attracted rising levels of public and private investment, and has grown at around 20 percent annually during the last decade. It has a key role to play in Asia and the world's low carbon future.

This chapter has examined the development of Asia's wind energy sector against the backdrop of its global development. It was shown how Asia only became a major player in the industry in the early 2000s but that it now enjoys an ever dominant position. China in particular has driven Asia's development, now accounting for over 80 percent of the region's installed capacity, and a third of the world total. The country has in addition become a major manufacturing hub for wind turbine assembly and component production, with five of the world's top ten turbine companies. Although India has too made significant investments in the sector, and now has the world's fourth highest installed capacity level, other large Asian economies – most notably Japan, South Korea, Taiwan and Indonesia – have fallen somewhat behind in installed power generation capacity from both a global and regional perspective. However, it should be noted that certain Japanese and Korean companies have become significant wind turbines producers and technology developers. Nonetheless, the pattern of Asia's wind energy development is highly asymmetric and ever more skewed towards China.

The factors behind Asia's successes, asymmetries and barriers to wind energy development were explored under four different thematic headings: technological and industrial; government policy and strategy; infrastructural challenges; institutional and socio-technical perspectives. To summarise, high rates of techno-innovation and market optimism concerning wind energy have made it a highly dynamic sector. However, in China the rapid expansion of wind energy installations has caused various problems and challenges. The country is developing wind farms at a very fast rate but large proportions of their capacity are not being absorbed by grid operators. As discussed, this has been as much a policy challenge as a technical infrastructural one, and where tensions between different energy sector stakeholders persist. Other forms of resistance to wind energy development in Asia is evident. In Japan, which in contrast to China and India has a relatively weak industry lobby for wind energy, the country's ten regional power companies (*Denjiren*) have reluctantly engaged with 'intermittent' wind power, even after the 2011 Fukushima nuclear disaster. In South Korea and other Asian nations, local opposition to proposed onshore wind farms and tough planning permission regulations have proved a notable obstacle to the sector's development. Yet, public support for cleaner energy in Asia is growing, especially in cities with acute air pollution problems. This is increasingly where Asia's population is concentrated. Furthermore, most Asian countries have signed the December 2015 COP21 Paris Agreement on climate change as well as implemented green energy and industrial policies, committing them to decarbonise their economic development as the 21st century progresses. Wind energy is currently one of the most important options for Asian and other countries to fulfil these obligations, and help create a cleaner and more sustainable energy future for all.

Notes

1 Dispatchable sources of electricity generation are those able to immediately respond to fluctuations in energy demand from power grids. This is not possible for renewables such as wind, solar and ocean energy given their generation intermittencies stemming from their dependence on variable meteorological phenomena such as wind flows and sunshine levels. However, hydropower, geothermal and bioenergy are not faced with this problem due to them offering constant energy streams like fossil fuels and nuclear.

2 Gigawatt. 1,000 kilowatts (kW) equal 1 megawatt (MW), and 1,000 MW equals 1 GW.

3 China Shipbuilding Industry Corporation, an example of how companies with relevant engineering competences have diversified into the wind energy sector.

4 *Clean Techia News*, 1 September 2016: https://cleantechnica.com/2016/09/01/pakistan-will-add-1-gw-wind-energy-capacity-2018/

5 These figures were 185.6 terrawatt-hours for the US and 185.1 terrawatt-hours for China.

6 *Business Green news*, 16 December 2015: www.businessgreen.com/bg/news/2439362/samsung-7mw-turbine-set-to-become-offshore-training-hub

7 In 1980, the typical cost range of wind energy generated electricity was US$0.60 to US$0.70 p/kWh but by 2011 had fallen to as low as US$0.05 p/kWh (IEA 2004; REN21 2012). Taking an illustrative example from China, operating generation tariffs in large-scale wind farms in Hebei and Xinjiang provinces were 3,850 yuan per MW in 2011, which compared to 6,200 yuan per MW capacity just a few years earlier in 2008.

8 A feed-in tariff (FiT) scheme normally involves government tariffs paid to producers both the generation or consuming of renewable energy electricity and/or supplying excess amounts back to the grid.

9 *Sun Wind Energy News*, 21st June 2012 [www.sunwindenergy.com/news/japan-feed-tariff-scheme-confirmed, accessed on 8 September 2016].

10 *Bloomberg News*, 30th March 2012 [www.bloomberg.com/news/2012-03-29/floating-windmills-in-japan-help-wind-down-nuclear-power-energy.html, accessed on 8 September 2016].

11 Windpower.net (2016) reported that by September 2016 China had 988 operational or under development wind farms, the average size of these farms being many times larger than in Germany, the US and other large producer countries.

12 *Recharge News*, 21st March 2012 [www.rechargenews.com/regions/asia_pacific/article307337.ece, accessed 7 September 2016].

References

Bloomberg New Energy Finance/BNEF (2011) *The Geopolitics of Clean Energy*, West Hartford: BNEF.

Bloomberg New Energy Finance/BNEF (2016) *2015 Global Wind Turbine Market Shares Report*, West Hartford: BNEF.

China National Renewable Energy Centre/CNREC (2013) *China Renewable Energy*, Vol 2(1), Beijing: CNREC.

Dent, C.M. (2014) *Renewable Energy in East Asia: Towards a New Developmentalism*, London: Routledge.

Fleming, P.D. and Probert, S.D. (1984) 'The Evolution of Wind Turbines: An Historic Review', *Applied Energy*, Vol 18(3), pp 163–177.

Gipe, P. (1991) 'Wind Energy Comes of Age: California and Denmark', *Energy Policy*, Vol 19(8), pp 756–767.

Global Wind Energy Council/GWEC (2007) *Global Wind Report 2006*, Brussels: GWEC Secretariat.

Global Wind Energy Council/GWEC (2009) *Global Wind Report 2008*, Brussels: GWEC Secretariat.

Global Wind Energy Council/GWEC (2012) *Global Wind Report: Annual Market Update 2011*, Brussels: GWEC Secretariat.

Global Wind Energy Council/GWEC (2013) *Global Wind Report: Annual Market Update 2012*, Brussels: GWEC Secretariat.

Global Wind Energy Council/GWEC (2014) *China Wind Power Report and Outlook*, Brussels: GWEC Secretariat.

Global Wind Energy Council/GWEC (2016) *Global Wind Report 2015*, Brussels: GWEC Secretariat.

Harborne, P. and Hendry, C. (2009) 'Pathways to Commercial Wind Power in the US, Europe and Japan: The Role of Demonstration Projects and Field Trials in the Innovation Process', *Energy Policy*, Vol 37, pp 3580–3595.

Inoue, Y. and Miyazaki, K. (2008) 'Technological Innovation and Diffusion of Wind Power in Japan', *Technological Forecasting and Social Change*, Vol 75, pp 1303–1323.

International Energy Agency/IEA (2004) *Renewable Energy: Market and Policy Trends in IEA Countries*, Paris: IEA.

International Renewable Energy Agency/IRENA (2012) *30 Years of Policies for Wind Energy*, Masdar City: IRENA.

Kaldellis, J.K. and Zafirakis, D. (2011) 'The Wind (R)evolution: A Short Review of a Long History', *Energy Policy*, Vol 36, pp 1887–1901.

Kang, J., Yuana, J., Hud, Z., and Xu, Y. (2012) 'Review on Wind Power Development and Relevant Policies in China During the 11th Five-Year-Plan Period', *Renewable and Sustainable Energy Reviews*, Vol 16, pp 1907–1915.

Lee, B., Iliev, I., and Preston, F. (2009) *Who Owns Our Low Carbon Future?: Intellectual Property and Energy Technologies*, London: Chatham House.

Li, J. (2010) 'Decarbonising Power Generation in China: Is the Answer Blowing in the Wind?' *Renewable and Sustainable Energy Reviews*, Vol 14(4), pp 1154–1171.

Li, X., Hubacek, K., and Siu, Y.L. (2012) 'Wind Power in China: Dream or Reality?', *Energy*, Vol 37, pp 51–60.

Liu, Y. and Kokko, A. (2010) 'Wind Power in China: Policy and Development Challenges', *Energy Policy*, Vol 38, pp 5520–5529.

Luo, G.L., Zhi, F., and Zhang, X. (2012) 'Inconsistencies Between China's Wind Power Development and Grid Planning: An Institutional Perspective', *Renewable Energy*, Vol 48, pp 52–56.

Maruyama, Y., Nishikido, M., and Iida, T. (2007) 'The Rise of Community Wind Power in Japan: Enhanced Acceptance Through Social Innovation', *Energy Policy*, Vol 35, pp 2761–2769.

Mizuno, E. (2014) 'Overview of Wind Energy Policy and Development in Japan', *Renewable and Sustainable Energy Review*, Vol 40, pp 999–1018.

National Development and Reform Commission/NDRC (2011) *China's 12th Five-Year Plan for Economic and Social Development*, Beijing: NDRC.

REN21 (2012) *Renewables 2012 Global Status Report*, Paris: REN21 Secretariat.

REN21 (2014) *Renewables 2014 Global Status Report*, Paris: REN21 Secretariat.

REN21 (2016) *Renewables 2013 Global Status Report*, Paris: REN21 Secretariat.

Roland Berger (2010) *From Pioneer to Mainstream: Evolution of Wind Energy Markets and Implications for Manufacturers and Suppliers*, Berlin: Roland Berger Consultants.

Ru, P., Zhi, Q., Zhang, F., Zhong, X., Li, J., and Su, J. (2012) 'Behind the Development of Technology: The Transition of Innovation Modes in China's Wind Turbine Manufacturing Industry', *Energy Policy*, Vol 43, pp 58–69.

Solidiance (2013) *China's Renewable Energy Sector: An Overview of Key Growth Sectors*, Shanghai: Solidiance.

Ushiyama, I. (1999) 'Wind Energy Activities in Japan', *Renewable Energy*, Vol 16, pp 811–816.

Ushiyama, I. (2012) 'Wind Power Development in Japan', presentation at the Japan Wind Energy Association, 9th March.

Windpower.net (2016) *Wind Energy Database*, Buc: Windpower.net (www.thewindpower.net)

Wiser, R. and Bolinger, M. (2010) *2009 Wind Technologies Market Report*, Washington DC: US Department of Energy.

World Wind Energy Association/WWEA (2012) *Quarterly Bulletin*, Vol 2(June), Bonn: WWEA Secretariat.

World Wind Energy Association/WWEA (2013) *Quarterly Bulletin*, Vol. 2(June), Bonn: WWEA Secretariat.

Xia, C. and Song, Z. (2009) 'Wind Energy in China: Current Scenario and Future Perspectives', *Renewable and Sustainable Energy Reviews*, Vol 13, pp 1966–1974.

Zhang, S. and Li, X. (2012) 'Large Scale Wind Power Integration in China: Analysis from a Policy Perspective', *Renewable and Sustainable Energy Reviews*, Vol 16, pp 1110–1115.

Zhang, S., Andrews-Speed, P., and Zhao, X. (2013) 'Political and Institutional Analysis of the Successes and Failures of China's Wind Power Policy', *Energy Policy*, Vol 56, pp 331–340.

Zhao, X., Zhang, S., Yang, R., and Wanga, M. (2012) 'Constraints on the Effective Utilization of Wind Power in China: An Illustration from the Northeast China Grid', *Renewable and Sustainable Energy Reviews*, Vol 16, pp 4508–4514.

Zhou, Y., Zhang, B., Zou, J., Bi, J., and Wang, K. (2012) 'Joint R&D in Low-Carbon Technology Development in China: A Case Study of the Wind Turbine Manufacturing Industry', *Energy Policy*, Vol 46, pp 100–108.