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Decarbonizing China's power system with wind power:

the past and the future

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Xin Li

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Abstract

Wind power in China has experienced significant growth since the beginning of this century. Total installed capacity has increased almost 300 fold – from 346 MW in 2000 to 91,413 MW in 2013. This rapid development has had two major drivers:

- First, the excellent wind power resource in China, especially in the north of the country, and the increasing competitiveness of wind generation worldwide.
- Second, favourable government policies such as: mandatory targets for major power generators in relation to renewable energy; the decentralization of plant approval rights; and feed-in tariffs for wind generation.

Along with the development of domestic wind turbine manufacturing capacity, these factors have stimulated the growth of wind power over the past 10 years or so. However, this rapid development has itself created new challenges. In particular, wind power has not been fully integrated into the electricity system as a whole, as the growth of wind generation capacity has not been matched by a corresponding growth in transmission capacity. This has resulted in a substantial requirement to curtail excess wind power, leading to the loss of a significant proportion (approximately 20 per cent) of potential wind output. To help with this problem, a number of transmission routes are planned, in order to link the wind farms in the interior to load centres on the coast. Nevertheless, it remains unclear whether the proposed expansion of the transmission system is adequate to accommodate the future growth of wind.

It is also unclear whether the existing pricing systems for electricity itself, and for electricity transmission, reflect the real costs involved. The rapid growth of wind generation has led to a growing deficit in China's renewable energy fund; this in turn is leading to uncertainty over payments to wind farm developers and turbine manufacturers. It can be argued that current pricing mechanisms do not give appropriate signals to encourage the integration of wind power into the electricity system as a whole – a problem which can only get worse as wind power expands further.

This paper highlights two options that could help the future development of wind power and its efficient integration into the electricity system: a more coordinated approach to the application of government policy in this area and the development of more market-based price signals in the power sector. Together these could provide a more coherent path towards the overall development of the power system and help secure the optimum contribution from wind power.

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Abbreviations

CERC	China Clean Energy Research Centre
CDM	Clean Development Mechanism
CEC	China Electricity Council
CfD	Contract for Difference
CHP	Combined Heat and Power
CNKI	China National Knowledge Infrastructure
CO_2	Carbon Dioxide
CREIA	China Renewable Energy Industries Association
CSPG	China Southern Power Grid
CWEA	China Wind Energy Association
DSM	Demand Side Management
EIA	US Energy Information Administration
ENTSO-E	European Network of Transmission System Operators for Electricity
FiT	Feed-in tariff
GDP	Gross Domestic Product
GW	Gigawatt (10^9 watt)
GWEC	Global Wind Energy Council
IEA	International Energy Agency
IP	Intellectual Property
kWh	Kilowatt hour (10^3 watt hour)
MEP	Ministry of Environment Protection
MST	Ministry of Science and Technology
NDRC	National Development and Reform Commission
NEA	National Energy Administration
OECD	Organization for Economic Co-operation and Development
SERC	State Electricity Regulatory Commission
SGCC	State Grid Corporation of China
TMP	Technology Management Plan
TSO	Transmission System Operators
TWh	Terawatt hour (10^9 watt hour)
TYNDP	Ten Year Network Development Plan
UHV	Ultra-High Voltage

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1. Introduction

The development of wind power in China is one aspect of an overall drive towards rebalancing the country's economy towards cleaner and more sustainable growth patterns. From an OECD perspective the most important issue is probably climate change and a key recent development here has been a series of announcements from leading Chinese policy makers that China's emissions would peak in the foreseeable future. For instance, during a visit by President Obama to Beijing, China's President Xi Jinping set a goal for China's CO_2 emissions to peak by around 2030 (Stanway, 2014). Similar statements were made by China's Vice Premier Zhang Gaoli in his opening speech at the New York Climate Summit (MEP, 2014) and by Premier Li Keqiang in the World Economic Forum in Tianjin (Xinhua, 2014) (both in September 2014).

These frequent references to an emissions peak from China's leadership are of immense importance for the global battle to address climate change. China's importance in the context of global greenhouse gas emissions is well known; it would be a key step towards putting the world on a more sustainable course if the country's emissions do indeed reach a peak and subsequently start declining. Furthermore, the goal is not just a matter of rhetoric: a number of policies have been implemented to decarbonize the country's energy system. It is important to note, however, that these measures have reflected not just concerns about climate change but also the wider concerns mentioned above; the announcements have involved such matters as the energy intensity of the Chinese economy and local air pollution. However, the various concerns are all pointing in the same direction; a number of policy trends are acting together and will have the effect of reducing CO_2 emissions, even when that is not the sole or primary goal.

The policies include a target announced by the State Council in 2009 for a reduction of CO_2 emission intensity per unit of GDP by 40–45 per cent by 2020, based on the 2005 level. China is already half way to achieving the 2020 target; by the end of 2013 its CO_2 emission intensity had been reduced by 28.5 per cent, which is equivalent to a reduction of 2,500 million tonnes of CO_2 compared to what would have been the outcome with the country's 2005 emission intensity (Reuters, 2014). In order to diversify China's fossil fuel-dependent energy structure, the *Twelfth Five Year Energy Development Plan* proposed an increase in the share of non-fossil fuels in total energy consumption: from 8.6 per cent in 2010 to 11.4 per cent in 2015 (State Council, 2013b). Other measures have included a target of reducing the energy intensity of GDP by 16 per cent under the current five year plan: from 1.034 to 0.869 tons of standard coal equivalent per 10,000 yuan[1] (State Council, 2012). There are also synergies with China's efforts to combat local air pollution – such as the State Council *Air Pollution Prevention and Control Action Plan* in September 2013 (State Council, 2013a). This plan aims at limiting emissions from industry and transport, promoting the development of low-emission and green technology industries, and promoting cleaner energy sources. It stipulated that the share of coal in total energy consumption would reduce to 65 per cent by 2017, and this has been reflected in the corresponding regional plans. For example, the Beijing–Tianjin–Hebei and surrounding regions issued implementing rules (MEP, 2013) proposing a reduction of total coal consumption by 83 million tons by 2017; coal would be replaced in these regions by increasing levels of power exchange with other regions, rising natural gas supply, and the development of non-fossil fuels.

It is not just the environmental consequences of excessive use of coal which concern China's policy makers. During the past 30 years, China's energy demand has been growing at 8 per cent annually. Domestic supply has not been able to keep up and a growing proportion of the country's energy demand depends on imports. For example, 57.4 per cent of crude oil, 30.5 per cent of natural gas, and 8.1 per cent of coal consumption were imported in 2013 (PeopleNet, 2014). Given the political

[1] The exchange rate was 1 US Dollar = 6.1144 yuan or 1 euro = 7. 675 yuan in November 2014.

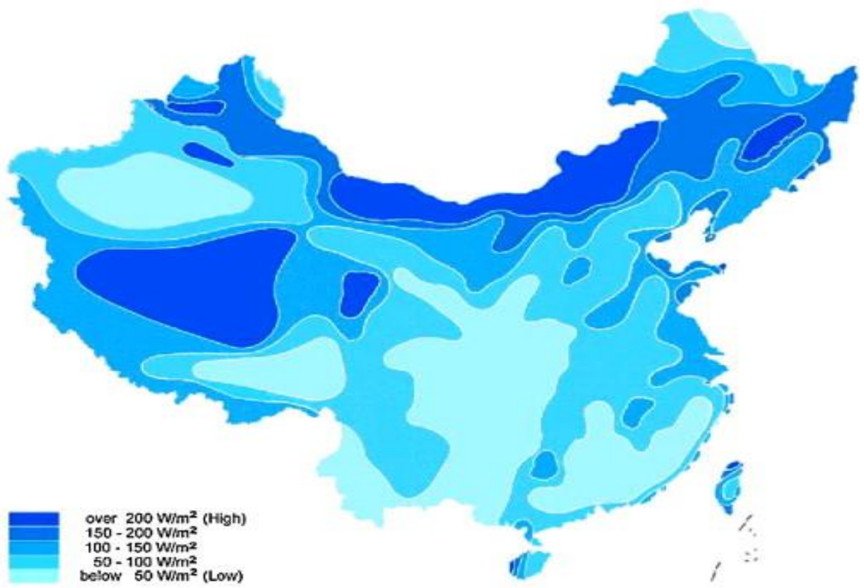
instability of oil exporting countries and the potential risks associated with transportation routes, policy makers have seen this trend as making China's energy supplies more vulnerable. Responses have included measures such as the 'going out' strategy under which China's energy companies have become actively involved in the exploitation and development of energy projects in foreign countries.

Thus wider concerns on environmental degradation and energy security, as well as the need to combat climate change, have acted together to reinforce policies aimed at the growth of domestically available and environmentally friendly energy sources in China, of which wind power is one of the most important. This paper looks at the development of wind power in China in recent years and the challenges posed by further advances in the sector.

2. Wind power potential in China

The challenges facing wind power in China do not primarily relate to the adequacy of the resource; the country has ample wind resources, sufficient in principle to power the entire nation. For example, assuming a guaranteed price of 0.516 yuan/kWh for wind power, McElroy et al. (2009) concluded that China's annual wind power generation could reach 6,960 TWh.[2] A survey by the China Meteorological Administration showed that exploitable onshore wind energy (at the height of 50 metres) amounts to 2,380 GW.[3] However, onshore wind resources are unevenly distributed, being concentrated in the north-east and north-west regions of China. For example, Inner Mongolia in the north of China accounts for about 60 per cent of the total onshore wind potential; other inland areas such as the south-west and north-west (Southern part of Xinjiang and northern part of Tibet) are home to the remaining potential (Zhao et al., 2009). Although China's offshore wind power has more limited potential (about 200 GW), it is still significant and offshore wind farms would be closer to the demand centres (such as cities in the coastal area of China). Figure 1 shows wind energy potential in China.

Figure: 1 Wind power potential in China



Source: Li and Gao (2007)

Given the huge potential and the policy context outlined above, wind power is expected to play an important role in the future power mix in China. The National Development and Reform Commission

[2] For comparison, total power generation was 5,245 TWh in 2013 (NBS, 2014).

[3] For comparison, total generation capacity was 1,247 GW at the end of 2013 (NEA, 2014a).

(NDRC), together with the International Energy Agency (IEA), proposed a wind energy roadmap for China up to 2050 (IEA/NDRC, 2011). Projected wind power generation capacity and the corresponding electricity generation are shown in Table 1.

Table 1: Targeted installed capacity, electricity generation and share of total electricity generation of wind power in China, 2020–50

Year	Generation capacity (GW)	Electricity generation (TWh)	Share of total electricity generation (%)
2020	200	400	5
2030	400	840	8.4
2050	1000	2200	17

Source: IEA/NDRC (2011)

Besides the significant potential for providing domestic power supply, wind power also offers substantial savings in CO_2 emissions. By 2011, power generation contributed 3.42 gigatonnes (or 44.1 per cent of the total) of CO_2 emissions in China (Li et al., 2014b). Wind power could help achieve significant reductions in this figure. For instance, a recent study by Feng et al. (2014) adopted hybrid life cycle analysis to examine eight power generation technologies in China. The authors suggested that life cycle CO_2 emissions per kWh for coal power generation and wind power generation are 1,230.0 and 46.4 grams/kWh, respectively.[4] Thus China could reap dual benefits in wind power development, namely by securing domestic supply and CO_2 emission reduction.

3. Wind Power Development since 2000

3.1 The experimental phase: 2000–2005

Although China started to invest in grid-connected wind power projects in the late 1980s, the growth of wind power capacity was initially slow. By the end of 2000, total wind generation capacity was only 346 MW.[5] The lack of supportive government policy, the high cost of wind power, the major reform of China's power system in the late 1990s, and the low price of fossil fuels all contributed to the slow growth of generation capacity.

The opportunity for wind power started to emerge in 2003. The NDRC implemented a *Concession Bidding Programme*, which aimed at promoting the development of domestic wind turbine manufacturing, decreasing the cost of generation, facilitating grid connection of wind farms, and achieving economies of scale through tender schemes (Li and Gao, 2007). As an initial experiment in facilitating the deployment of wind turbines, the Programme drove the increase of wind power capacity from 546 MW in 2003 to 743 MW in 2004. However, despite its significance in promoting capacity growth, the Programme was criticized in terms of its selection criteria, which weighted bidding price more heavily than other factors – such as the financial and technical capabilities of investors and the strategic planning of the project (Li et al., 2008).

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[4] The study used a combination of input–output analysis and life cycle analysis to estimate the CO_2 emissions per kWh of coal, oil, natural gas, hydropower, nuclear power, wind power, solar PV, and biomass in China. The national input–output table is used; this captures the entire supply chain of the Chinese economy. The life cycle inventories of the eight power generation technologies are from the Eco-invent database, which lists the different materials used for the construction of power plants. The combination of input–output analysis and life cycle analysis captures both the direct emissions (e.g. coal combustion) and the indirect emissions (e.g. use of steel and cement for wind farm construction).

[5] All wind power capacity figures quoted are for installed capacity, unless specified otherwise.

In response to these criticisms, the NDRC issued a *Notice on Wind Power Plant Construction and Management* in 2005. The Notice revised the selection criteria, downgrading the weight allocated to bid prices to 40 per cent. It emphasized that the approval of wind farm projects should also be based on the scale and location of wind farms – factors which have to be coordinated with power system operation and power grid capability. Nevertheless, unrealistically low bid prices were still apparent during the bidding process. For example, Li et al. (2006) pointed out that the winning bid prices (from 0.379 yuan per kWh to 0.519 yuan per kWh) were significantly lower than the actual cost of wind power (which they estimated as being between 0.566 and 0.703 yuan per kWh) in the concession bidding system between 2003 and 2006.

The Notice also clarified the respective responsibilities of national and regional development reform commissions, in order to speed up procedures for the approval of wind farm projects. For wind farms with less than 50 MW of generation capacity, regional development reform commissions were in charge of the approval processes. This created a '49.5 MW phenomenon', under which most new wind farms had a generation capacity of 49.5 MW. However, due to decentralized project approval, total wind capacity reached 1,250 MW by the end of 2005. In addition, in order to promote the growth of domestic wind turbine manufacture, the Notice also established a mandatory requirement that domestic equipment make up at least 70 per cent of wind power facilities; this created a foundation for the subsequent development of the Chinese wind power industry.

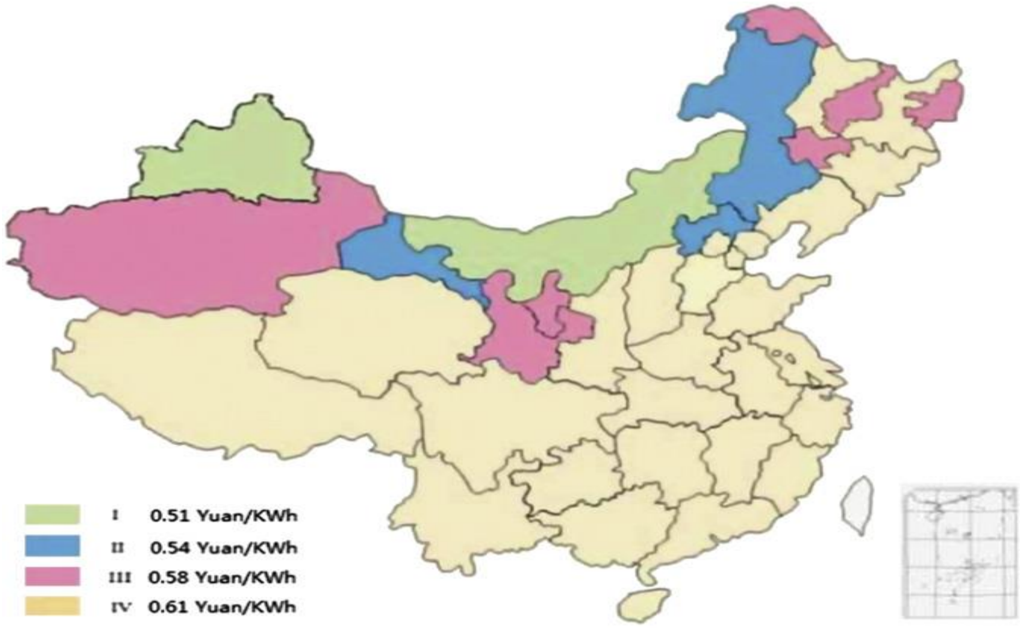
3.2 The take-off phase: 2006–2010

But real take off began in 2006. The *Renewable Energy Law*, promulgated in 2006, provided a strong basis for the development of renewable energy in China. The Law clarifies the obligations and responsibilities of stakeholders (which include local authorities, electricity regulatory commissions, grid operators, and investors). It prioritizes the development of renewable energy sources over that of other energy sources and provides that the extra costs of renewable energy should be collected from a surcharge on power sales. It also establishes specific funding to support research and development in renewable energy technologies and to support decentralized renewable energy systems in remote areas.

Following the *Renewable Energy Law*, a target for renewable energy development was presented in the *Medium–Long Term Development Plan for Renewable Energy* in 2007. Total wind power generation capacity was predicted to reach 5 GW in 2010 and 30 GW by the end of 2020. Electricity operators with installed electricity generation capacity of over 5 GW were 'requested' to install 3 per cent of their total generation capacity from non-hydro renewable sources by 2010 and 8 per cent by 2020 (NDRC, 2007). These requests were, in practice, mandatory targets applied to the major power generators, which included the top five power groups: China Huaneng Group, China Datang Corporation, China Guodian Corporation, China Huadian Corporation, and China Power Investment Corporation. The measures made wind power projects in wind resource-rich areas with convenient access to the power grid very attractive to these power generators. Liu and Kokko (2010) recognized the mandatory target as being '*more effective for promoting wind power than any of the incentives operating through the pricing system*'.

After years of experimenting with wind power pricing in the *Concession Bidding Programme*, NDRC issued a *Notice on Improving the Pricing Policy of Grid-Connected Wind Power* and finalized the pricing mechanism for wind power in 2009. Wind power prices were classified into four categories, namely 0.51, 0.54, 0.57, and 0.61 yuan/kWh, according to the potential of wind resources and conditions of wind farm sites (better conditions and higher potential meant lower prices). Figure 2 illustrates regional wind power price differentials in China.

Figure 2: Regional differences in the unit cost of wind power in China



Source: Yang et al. (2012)

The early development of wind power mostly happened in onshore areas, which have lower financial and technical requirements. Offshore wind power, although it has more limited potential, is usually situated closer to the developed coastal markets. The development of offshore wind power started to emerge in 2010, when the *Notice on Offshore Wind Power Plant Construction and Management* was issued by the NDRC. The Notice set out the regulations that will apply to offshore wind projects, together with the responsibilities of national and regional authorities in offshore wind power construction and management. It also covered issues such as those regarding project planning and approval, wind farm construction and operation, and environmental impact assessment. Nonetheless, as discussed below, offshore wind power is only just starting to develop.

Overall, however, the measures discussed above had a major impact on the growth of wind power capacity. Between 2006 and 2010, total installed capacity increased almost 20 fold, from 2,537 MW to 44,734 MW.

3.3 From quantity growth to quality growth: 2011–present

The boom in capacity growth resulted in concerns about the effectiveness of wind power's integration into the electricity system. One of the main obstacles was the lack of unified technical standards – though this has, to a large extent, been addressed since 2011. The National Energy Administration (NEA), the Ministry of Science and Technology (MST), and other authorities have promulgated a number of regulations and policies to address the issues; these include technical standards, wind power integration, and wind farm management. For example, in March 2011 the NEA issued *Technical Standards on Large-scale Wind Power Grid Integration* and *Regulations on Wind Power Technology Integration into Wind Power System.* In 2012, the MST issued *The Development of Wind Power Generation Technology: Specific Planning for the Twelfth Five Year Period.* All of these regulations and policies focused on improving the technical standards for wind power development.

Another obstacle, ascribed to the decentralized approval procedure, has been the uncoordinated deployment of wind turbines. In August 2011, the NEA issued *Interim Measure for the Management of the Development and Construction of Wind Power*, which aims to promote the orderly development of wind power and standardize the construction procedures. Under this Measure, regional authorities must submit wind power project proposals to the NEA before final approval. Subsidies are only allocated to those wind power projects that have been registered with the NEA; other projects are not eligible for government funding or for connection to the power grid. Following the Measure, a first phase of wind power projects (with total approved wind power capacity amounting to 28.83 GW) was approved by the NEA at the end of August 2011. In all, the NEA has approved four phases of wind power projects with total installed capacity over 100 GW.[6]

Initially, however, the Measure did not dampen regional authorities' enthusiasm for wind power, given that the growth of wind power increases their tax revenues and creates employment for local people. (For example, the wind power industry has created 6,000 new jobs in Inner Mongolia, according to the *Inner Mongolia Twelfth Five Year Wind Power Development Plan*.) Also, the major power generators were enthusiastic about wind projects as a means of fulfilling their mandatory targets (as mentioned in Section 3.2). In the initial stages after the Measure was introduced, some wind power projects that had not been registered with the NEA were still authorized by local government. As a result, in early 2012, the NEA required all regional authorities to implement the Measure more strictly. It also stipulated that regions where there were curtailments[7] of more than 20 per cent of wind generation output were not, in principle, allowed to initiate new wind power projects.

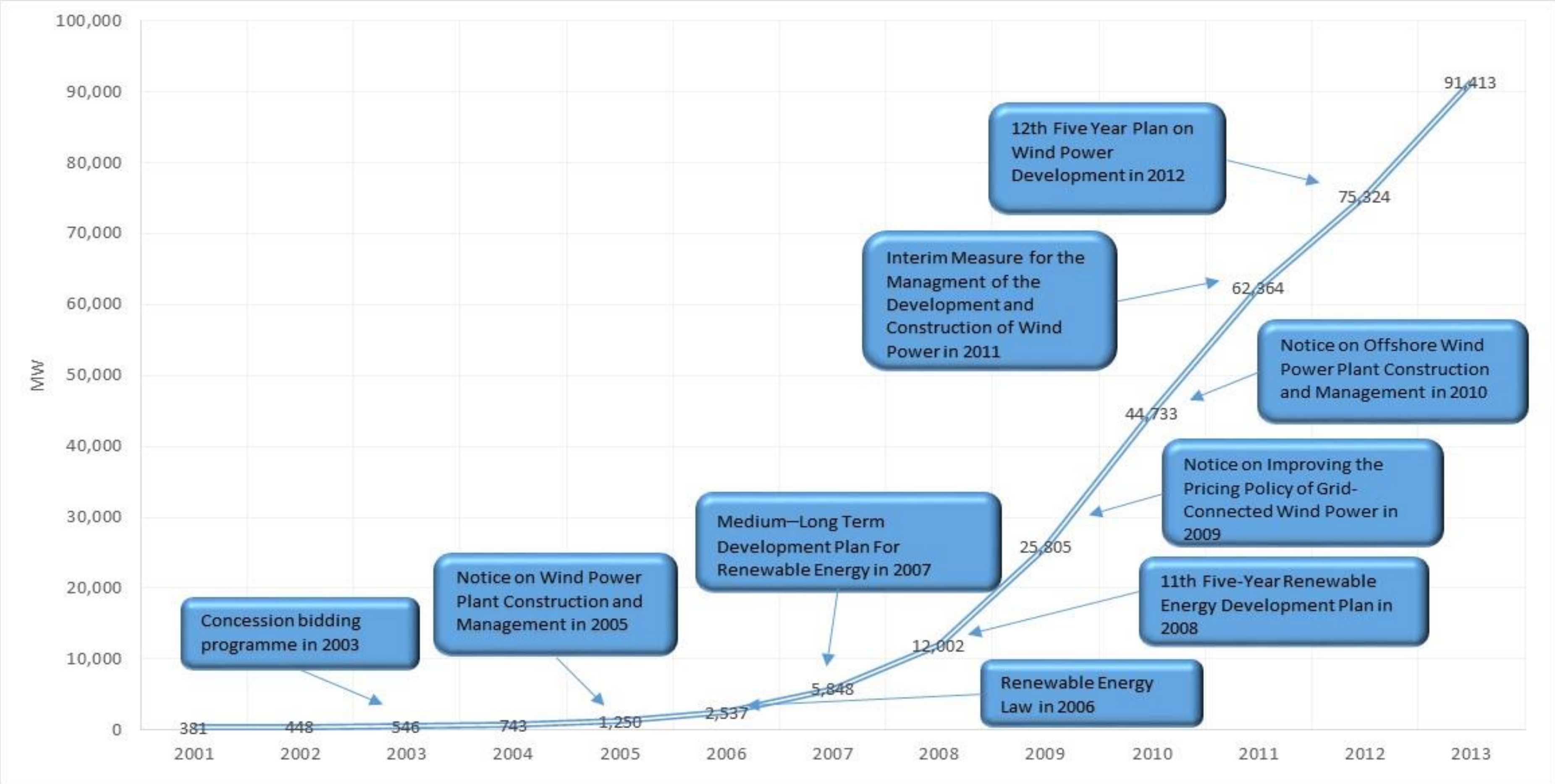
In 2012, the *Twelfth Five Year Plan on Wind Power Development*, prepared by the NDRC, provided forecasts of wind power installed capacity for the decades ahead. It projects that wind power generation capacity would reach 100 GW by 2015 and 200 GW by 2020, of which offshore capacity would account for 30 GW. At present, offshore wind power is still at the demonstration stage; only 0.43 GW, or 0.5 per cent of the total installed capacity, had been installed (in Jiangsu, Zhejiang, and other coastal areas) by the end of 2013. However, to follow up the plan, the NDRC produced *A Notice on Offshore Wind Power feed-in tariff* in June 2014; this sets the fixed tariff for new near offshore and intertidal wind power projects at 0.85 yuan/kWh until 2017 (the price does not change before the end of 2017). The tariff will be adjusted after 2017 in line with improvements in the technology and reductions in capital costs. Although it will be difficult for China to achieve the 5 GW offshore wind target by 2015 (set in the Twelfth Five Year Plan on Wind Power Development) it is expected to reach 65 GW in 2030 and 200 GW in 2050, respectively (IEA/NDRC, 2011).

Figure 3 shows the accumulated installed capacity and the corresponding government policies since 2001. With 45,894 wind turbines installed, total wind power generation capacity had reached 91,413 MW by the end of 2013 (CWEA, 2014).

[6] The figure of 'over 100 GW' is the total approved capacity since the Measure was issued and is the sum of the four phases of capacity approval. NEA approval enables wind farm developers to initiate construction and entitles the projects to receive subsidies. It does not necessarily mean that the wind farms concerned have been constructed; the figure is different from that for total installed capacity in any given year.

[7] Curtailment means the process of denying access to the grid for generated electricity when supply and demand are balanced.

Figure 3: China's wind power generation capacity growth and the selected government policies between 2001 and 2013



Source: Wind power generation capacity is from (CWEA, 2014), Figure 1.

4. Development of domestic manufacturing capacity

In addition to the considerable wind power potential and favourable government policies, some studies have pointed to the growth of domestic wind turbine manufacture (with its increasing productivity and technical capability) as a factor in wind power development in China (Li et al., 2010, Zhao et al., 2009). Lema and Ruby (2006), for instance, conducted a case study in China to evaluate the significance of the development of domestic wind turbine manufacturing. They identified two policy phases. Before 2000, the Chinese government aimed mainly at encouraging the rapid deployment of wind turbines and maximizing the environmental and economic benefits of wind power development, rather than at encouraging manufacture as such. However, as indicated above, the growth of wind power generation capacity was not actually significant at that stage. After 2000, a new policy model was implemented, to encourage the expansion of the domestic wind power manufacturing industry. The authors argued that this new policy model helped maximize the potential of wind power development and that it could form a model for countries with appropriate capabilities in such areas as finance, technology, and resources.

One of the reasons for promoting domestic wind power capacity is that it has helped to reduce the capital cost of wind farms significantly. Li and Gao (2007) found that domestically produced wind turbines and components were 20 per cent cheaper than their foreign counterparts – very significant as the cost of wind turbines and components accounts for approximately 70 per cent of the total cost of wind power projects. By the end of 2012, 17 out of the top 20 wind turbine providers were domestic Chinese companies, and they account for 90 per cent of the total wind power generation capacity (CWEA, 2013), a considerable increase from the 2006 figure of 30.9 per cent (Shi, 2007). Furthermore, the development of domestic manufacture has driven the 'going out' of China's wind power industry since 2008. By the end of 2013, domestic manufacturers had exported 1,392.5 MW of wind turbines to 27 countries (Li et al., 2014a). It is believed the development of China's wind manufacturing industry, in both domestic and international markets, could help to drive down the costs of wind turbines and make wind power more accessible (Mathews and Tan, 2014).

Müller et al. (2010) analysed the role of EU investors in Chinese wind power development. The authors argued that the collaboration between China and EU Member States built a political platform that facilitated the growth of China's wind turbine manufacturing industry. In the early stages, technology transfer provided the technical foundation for a local manufacturing base. Later, advanced technology was brought into China through licensing, joint ventures, and mergers between Chinese and European companies. The growth of China's wind power manufacturing base significantly reduced the overall costs of wind turbines. The collaboration also provided financial support to wind farm development, mainly via the Clean Development Mechanism (CDM).

However, the collaboration has experienced a number of challenges, most being related to the transfer of intellectual property (IP). Müller et al. (2010) point out that the European partners have concerns about the loss of intellectual property during the technology transfer, whilst the Chinese counterparts believe that EU companies do not wish to transfer the 'know how'. Similar concerns have also been expressed in other USA–China clean energy collaborations. The issue is examined in Lewis (2014) which looks at cross-border clean energy collaboration, focusing specifically on the case of the USA–China Clean Energy Research Center (CERC). The CERC is a virtual centre, established in November 2009. It aims to enhance cooperation between China and the USA in the field of clean energy technology innovation, energy efficiency improvement, low-carbon economy transition, and climate change mitigation and adaptation. One of the unique features of the CERC is the creation of intellectual property through joint R&D, which distinguishes it from USA–China clean energy collaboration. A total of at least $150 million has been committed by public and private funding over five years, contributed equally by the two countries. The initial collaborative clean energy research focuses on advanced coal technology, clean vehicles, and building energy efficiency.[8]

The establishment of the CERC was considered as a means of reducing the risk of IP disputes. A Technology Management Plan (TMP) was established in negotiations between government agencies from both countries. It details the IP rules for participation and must be signed by each participant. The TMP states the rights and responsibilities of background IP owners, which include the rights of retaining *all right, title and interest in their background IP and* no requirement to *license, assign or otherwise transfer IP.* Trade agreements, patents, and state secrets are protected, although the TMP requires disclosures in the form of public reports. Thus, the TMP is designed to reduce the risk of IP sharing; it also addresses the issue of uncertainty in the creation of new IP, covering issues regarding ownership of the new IP (by sole or joint research activities), data and information sharing, as well as possible IP disputes.

However, despite the establishment of the CERC, there has been little IP creation involving collaboration between US and Chinese participants. Participants tend to avoid getting into areas that may trigger IP rights disputes when designing their research programmes. The establishment of the CERC has thus not really changed the attitude of Chinese or US participants to the sharing of IP. There are persistent IP protection concerns that have driven a number of large corporations to withdraw from the CERC.

Despite efforts to address the problem, IP issues remain an obstacle to collaboration between Chinese and OECD companies. It is therefore likely that China will continue to rely predominantly on domestic technology in the future development of its wind resources.

5. Wind power development – the way forward

5.1 Concerns on wind power transmission

China's substantial growth in power generation capacity only tells half of the story. Wind power output has not always matched the capacity growth. In fact, a significant proportion of wind output has been curtailed by grid operators. For example, curtailment reached 16.2 TWh in 2013. Table 2 shows the amount of curtailment and the ratio of curtailment to total wind power generation in different regions in 2013.[9]

Table 2: A breakdown of wind power curtailment in 2013

Region	Power Curtailment (TWh)	Ratio of curtailment to total wind output (%)
East Inner Mongolia	3.4	19.5
Gansu	3.1	20.7
West Inner Mongolia	3.0	12.2
Hebei	2.8	16.6
Jilin	1.6	21.8
Heilongjiang	1.2	14.6
National	16.2	10.7

Source: adjusted from (Li et al., 2014a) Table 2–9.

[8] For details of the CERC, refer to www.us-china-cerc.org/index.html.

[9] For comparison, the curtailment level of wind power in the other countries is much lower. For example, in the USA, curtailment levels in different areas are usually in the range between 1% and 4% (Bird et al., 2014); in Germany, the curtailment level was 0.71% in 2012 (Bundesnetzagentur, 2014); in the UK, the curtailment level was 0.5% in 2012 (Daubney, 2013).

The majority of the curtailment happened in provinces in the three northern regions: Inner Mongolia, Gansu Hebei, Jilin and Heilongjiang. It can be ascribed to a number of factors:

- First, the mandatory target relates to the share of renewable energy sources in generation capacity, not generation (i.e. kW not kWh). This has driven the major power generators – which accounted for 55 per cent of total wind power capacity that is integrated into the grid[10] (about 43 GW) by the end of 2013 (Li et al., 2014a) – to focus on locations endowed with good wind resources. Local authorities in these regions also encouraged the development of wind farms to create jobs and increase local tax revenues. Thus, there was strong pressure for the rapid growth of wind power capacity in specific areas.

- Second, the regions concerned are relatively underdeveloped and the growth in local power demand has not kept pace with the growth in power supply. For example, total power generation in Inner Mongolia was 317.2 TWh in 2012, whilst total power consumption was 201.7 TWh. In the same year, Gansu's total power supply was 110.3 TWh, while demand was 99.5 TWh (CNKI, 2014).

- Third, the wind-rich regions have relatively inflexible power generation and, in particular, a lack of load-following units. Combined Heat and Power (CHP) generators account for a significant proportion of the total in these northern regions and they are used for district heating in the winter, which means they operate as 'must run' plants. For example, CHP generation accounted for approximately 90 per cent of total capacity in Jilin (Li et al., 2014a). The heat plants have to maintain operation during the period of heat supply in winter, when wind power output also peaks, leading to a higher level of curtailments during the winter months (See Table 3).

Table 3: Monthly wind curtailment ratio by province (1st half 2012)

	January	February	March	April	May	June	Average
Jilin	30.5%	34.8%	42.5%	30.3%	19.5%	11.0%	28.1%
East Inner Mongolia	24.1%	27.9%	23.6%	22.3%	12.7%	6.1%	19.4%
Gansu	25.3%	25.7%	20.9%	14.2%	14.2%	10.5%	18.4%
West Inner Mongolia	25.8%	26.1%	24.5%	9.6%	5.1%	4.9%	16.0%
Liaoning	23.6%	20.4%	19.1%	13.8%	3.5%	1.4%	13.6%
Heilongjiang	19.2%	20.2%	22.3%	15.9%	2.7%	0.8%	13.5%

Source: Davidson (2014)

In principle, these curtailments should lead to compensation payments. Articles 14 and 29 of the *Renewable Energy Law* stipulate that grid operators are legally responsible for purchasing all power output from renewable energy sources and are liable for compensating the economic losses if not all outputs are purchased. Taking the wind power curtailment in 2013 as an example, the total curtailment of 16.2 TWh could result in a total loss of 8.3 billion yuan to wind farm developers under the lowest FiT tariff of 0.51 yuan/kWh. In practice, however, it is not clear whether the law has been strictly enforced; there is some evidence that wind farm developers are suffering economic losses due to curtailment (Xiao, 2014), which implies that compensation is not always paid by grid operators to wind farm developers.

[10] Wind power capacity that is integrated into the grid is different from installed capacity. It refers to the capacity that is already in operation and is able to deliver electricity to the power grid. Installed capacity refers to the capacity that is already deployed but may or may not be integrated into the grid.

Due to their significant wind power potential, the future development of wind power will still rely on the three northern regions. Table 4 presents a breakdown of China's wind power target between 2020 and 2050 at regional level. The three northern regions are expected to continue to account for the majority of wind capacity.

Table 4: Scenarios for wind power development in China between 2020 and 2050 (Unit: GW)

Regions	2020	2030	2050
Western Inner Mongolia	40	100	300
East Inner Mongolia	20	40	90
North-eastern China Provinces (Heilongjiang, Jilin and Liaoning)	30	38	60
Hebei	15	27	60
Gansu	20	40	120
Xinjiang	20	40	100
Eastern, Central China and other areas, onshore	25	50	70
Near offshore wind	30	60	150
Far offshore wind	0	5	50
Total	200	400	1000

Source: IEA/NDRC (2011)

Given the above situation, it is inevitable that there will continue to be supply that is surplus to demand in the producing regions. This surplus will need to be delivered to the load centres in the eastern regions. At present, the eastern regions account for 50.7 per cent of total power demand in China, compared to 23.3 per cent in the western regions, 19.3 per cent in central China, and 6.8 per cent in the north-east (NEA, 2013a). Although the convergence of regional development may result in a relative decline in its share of national power consumption, the eastern area will still be the major power consumer, at least until 2050 (IEA/NDRC, 2011). Furthermore, the *Air Pollution Prevention and Control Action Plan* and its corresponding policies will have the effect of limiting the growth of electricity supply from coal power in eastern regions. For example, according to the *Energy Saving and Emission Reduction Planning on the Advancement and Upgrade of Coal Power Plants*[11] (2014), it is forbidden to construct any new coal power plants in the provinces of Beijing, Tianjin, and Hebei, the Yangtze River Basin, and the Pearl River Basin, except for combined heat and power plant (NDRC, 2014).

Thus, the first major concern for the future development of wind power is the need to transport wind power from wind-rich regions to the demand centres.

5.1.1 Proposed transmission corridors

Since the power system reform of the early 2000s, almost all of China's power grid assets have been owned and operated by two grid companies: the State Grid Corporation of China (SGCC) and the China Southern Power Grid (CSPG). The two grid companies are responsible for power grid planning, investment decision-making, operation and maintenance of grid infrastructure, and power transmission and distribution.

A number of transmission corridors aimed at linking the wind-rich regions to the load centres are planned by these two companies. For example, for Inner Mongolia, four transmission corridors using ultra high voltage (UHV) technology are proposed: two corridors linking East Inner Mongolia to

[11] The *Air Pollution Prevention and Control Action Plan* sets the general aim of mitigating air pollution in China. A number of related policies are put forward in order to address specific industries or specific regions. The *Energy Saving and Emission Reduction Planning on the Advancement and Upgrade of Coal Power Plants* is one of these policies.

Shandong and Jiangsu with transmission capacity of 9 GW and 8 GW, respectively; a further two corridors linking West Inner Mongolia to Tianjin and Shaodong with transmission capacity of 6 GW and 8GW, respectively. With a total investment of 80 billion yuan, these four transmission corridors will be completed in 2017 and 2020, respectively. For Gansu, one UHV direct current transmission route is proposed to link Jiuquan (Gansu) to Hunan with a total length of 2,413 km. It worth noting that all the proposed transmission corridors are planned to transport a combination of conventional and renewable energy production rather than to act as wind-specific transmission corridors.

These transmission corridors are collectively known as the 'West–East Electricity Transfer Project'.[12] According to the IEA/NDRC (2011), transmission capacity between the west and the east will reach 300 GW by 2020 and 400 GW by 2030 and will remain steady until 2050.[13] The main questions relating to wind power transmission capacity are: whether wind power will be given priority in power transmission systems, how much capacity is reserved for wind power, and whether the planned transmission capacity is sufficient for the future growth of wind power. At present, there are no clear answers to these questions.

5.1.2 Transmission pricing

Grid companies are responsible for the construction of the transmission system. The investment is recovered via a regulated transmission price set by the Price Bureau of the NDRC for each specific transmission corridor. According to the *Provisional Measures on Transmission and Distribution Price Setting* in 2007, the transmission price is determined by a combination of approved costs, approved income, and tax payable (SERC, 2007). The price bureau of the NDRC is currently responsible for price approval.

The transmission price is defined according to the type of transmission project. In general, there are two types of transmission project: the first category consists of point-to-grid projects, such as the transmission lines linking the Three Gorges Dam to Shanghai, Jiangsu, and Zhejiang; the second category consists of grid-to-grid projects, (power exchanges between power grid regions).

Wind power transmission is considered to fall within the category of grid-to-grid projects, for which transmission prices have been defined. According to the SGCC (SGCC, 2014), wind power transmission from the north-east grid to the north grid amounted to 4 TWh in 2013, approximately one-quarter of total power trade between these two regions. The transmission price was set at 0.0243 yuan/kWh based on the normal rules for transmission price setting for power trade between these grids. Similarly, wind power trade between Gansu, Ningxia, Xinjiang, and Shandong amounted to 3.3 TWh in 2013. It is considered as grid-to-grid power trade between the north-west grid and the Shandong power grid, for which the transmission price is set at 0.06 yuan/kWh. Given that wind power accounted for a small proportion of cross-regional power transmission, the adoption of current transmission prices appears reasonable (with the assumption that the small size of the volumes implies that there has been no need for major grid investments to transport the wind power). For instance, cross-regional wind power trade amounted to 10 TWh among the SGCC-controlled areas in 2013, while the total cross-regional power trade was 647 TWh.

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[12] The West–East Electricity Transfer Project was initiated in the early 2000s and is part of the West Development Programme in China. The project aims to promote the growth of the less developed western areas. By transferring excess power generation to the load centres, it could also alleviate the power shortage of the eastern areas. In recent years, due to severe environmental problems in the eastern regions, west–east electricity transfer has been growing. Large-scale coal power developments are proposed in regions endowed with coal reserves. These regions include Inner Mongolia, Xinjiang, and Gansu – which are also endowed with wind resources.

[13] This is a projection of the total inter-regional electricity transmission capacity between the West and the East, and it does not distinguish between UHV and other types of transmission system.

However, the future growth of wind capacity in the three northern regions would require the upgrade of transmission infrastructure in both capacity and length, which could lead to an increase in transmission costs. According to a projection by IEA/NDRC (2011), the cost of grid connection and long-distance transmission of wind power could range between 0.05 and 0.30 yuan/kWh in China, depending on the location of wind farms. The wind power trade between Gansu, Ningxia, Xinjiang, and Shandong represents the longest transmission route in China, but the current transmission price (0.06 yuan/kWh) is still at the lower end of the IEA/NDRC's projection. Thus, it is likely that the current transmission pricing mechanism does not reflect the real cost of future wind power transmission. Note, however, that the real transmission costs in China (not just those for wind power transmission) have always been obscure. For instance, a government report on the regulation of transmission and distribution costs in different regions showed that, besides depreciation and the costs of materials and labour, an item called 'Others' accounted for over a quarter of the total costs in most regions. It is not clear what this category includes (Yu, 2014). Furthermore, the report concentrated on the overall costs of transmission and distribution at regional or provincial level. Thus the information available on specific transmission projects is limited.

5.2 Concerns on the economics of wind power integration

5.2.1 The pricing of wind power

In addition to the question of transmission pricing, the economics of wind power consumption in the importing regions are also dependent on electricity pricing mechanisms, given that the costs of wind power are higher than the costs of conventional power generation and that importing regions pay an energy price in addition to transmission costs. As mentioned in Section 3.2, wind power prices are classified into four categories, ranging from 0.51 to 0.61 yuan/kWh. Wind power prices are then separated into two parts:

- grid companies pay the average on-grid coal power price to purchase wind power:[14] this is the amount paid by the importing regions;
- the gap between the average on-grid coal power price and the regulated wind power price is paid by the renewable energy fund.

The renewable energy fund is financed by imposing a surcharge on all power sales except residential and agricultural sales. The fund also covers the cost of building new power lines to feed the wind farms into the grid. This subsidy is distributed according to the length of new power lines and the volume of generation; it is set at 0.01 yuan/kWh for up to 50 km of new power lines, 0.02 yuan/kWh for 50–100 km, and 0.03 yuan/kWh for over 100 km of new power lines.

Under the current pricing mechanism, importing regions will benefit from large-scale long-distance transmission. Taking the trade between the north-east grid and the north grid as an example, regardless of the power source, the regulated price that the importing north grid had to pay was 0.3857 yuan/kWh in 2013 (SGCC, 2014). This price was lower than the lowest average on-grid coal power price of the north grid (for example: 0.3887 yuan/kWh in Shanxi).

Due to the rapid development of renewable energy in recent years, the deficit in the renewable energy fund has been increasing – from 1.3 billion yuan in 2009 to 20 billion yuan in 2012 (Xinhua, 2013). In an attempt to reduce the deficit, the surcharge on power sales has been adjusted five times since 2006, from 0.001 yuan/kWh to 0.015 yuan/kWh in 2013, but the deficit remains. In any event, despite

[14] The most recent average on-grid coal power price ranges between 0.2791 yuan/kWh in Ningxia to 0.502 yuan/kWh in Guangdong. The average on-grid coal power price is a benchmark price set by the national Price Bureau. Power plants can negotiate with their provincial Price Bureau to adjust the benchmark price, according to the condition of the power generation units. Thus, the on-grid price for each power plant within a given province is slightly different.

the increase in the surcharge, there have been significant delays in payments to wind farm developers (up to 20 months), which in turn have led to delays in payments to wind equipment manufacturers (Pu, 2012). Furthermore, the renewable energy fund deficit has been increasing even at a time when many renewable energy sources, such as solar power, have still been at an early stage of development. Solar power prices range between 0.9 and 1.0 yuan/kWh, almost double the wind power price. With a solar capacity target of 35 GW in 2015 and 100 GW in 2020, the renewable energy fund deficit is only likely to increase further, with the risk of further delays in payments to wind farm developers and wind equipment manufacturers.

One possible effect of the above situation is to create incentives for the building of a national carbon trading system,[15] in which eastern regions could offset their emissions by providing financial support to wind farm developers in the three northern regions. In the past, China's approach to achieving energy and emission targets has relied mainly on administrative measures. For example, some regions in China resorted to blackouts in order to achieve the 20 per cent energy intensity reduction target at the end of the Eleventh Five Year Period. The blackouts caused great disruption to industrial production and people's daily life. Since then, in the Twelfth Five Year Period, the Chinese government has promoted the establishment of market-based instruments to ensure the achievement of energy and environmental targets (Han et al., 2012). For instance, the Twelfth Five Year Plan includes a call to 'gradually develop a carbon trading market'. Carbon trading pilots were initiated in seven provinces and cities in 2011.

China has also been a major host for CDM projects. By the end of September 2014, China had 3,963 registered CDM projects in total; 1,525 were wind power projects. Either a CDM type of carbon trading programme, or the wider development of a national carbon trading system, would provide ways of helping China's affluent eastern regions to offset their emissions through purchasing emission certificates from wind-rich regions, while at the same time relieving the financial difficulties of wind farm developers.

5.2.2 The pricing of other parts of the power system affected by wind power development

Wind power is not a stand-alone energy source. The integration of wind generation into the power system has an impact on the operation of other parts of the system. For example, it leads to a higher requirement for peak shaving services from thermal power plants. In order to encourage power suppliers to provide the peak shaving services, thermal power generators are compensated on a basis determined by the regional power grid. For example, north-east thermal units are compensated at 0.5 yuan/kWh for operating at less than 40 per cent of their operational capacity. The costs of compensation are distributed across thermal power plants within the regional power grid according to their shares in total power generation. Given that large-scale thermal units are more capable of providing this service, the current compensation system tends to disadvantage smaller thermal units (Zhao et al., 2013). An example in Zhao's study showed that a majority (seven out of eleven) of thermal power plants have to pay for the compensation.

The use of demand side management (DSM) could also help the integration of wind power by accommodating the variability of wind output. Moura and de Almeida (2010) discussed the role of DSM in the integration of wind power in Portugal and found that DSM measures can be effective in reducing consumption during peak load hours when wind outputs are at a low level. DSM was first introduced in China in the early 1990s. It is considered an effective way of improving energy efficiency, managing load, and reducing or postponing investment in new capacity and transmission. Hu et al. (2005) gave an account of the implementation of DSM in China in the early 2000s. For example, load management tools – such as time-of-use pricing and peak-load pricing – are used to alleviate problems related to peak demand. In 2011, the *Administrative Measures in DSM Implementation* introduced energy saving targets and peak load reduction targets for Chinese utility companies. These Measures stipulate a reduction target of 0.3 per cent in terms of energy, equivalent to 14 billion

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[15] For a brief discussion of China's carbon trading system, refer to Ellermann and Böning (2014).

kWh of electricity in 2011, and a 0.3 per cent reduction in terms of load, reducing peak load by 1,900 MW in 2011.

However, there are a number of challenges facing the promotion of DSM. In particular, there are no adequate economic incentives to mobilize the participation of the various parties involved. For example, the *Orderly Use of Electricity Plan* in 2011 was introduced to manage power shortages and unscheduled blackouts. It adopted demand response approaches – such as peak load shifting and load shedding – to maintain stable power supplies. However, no incentive was provided to encourage a demand response from consumers. The benefits from implementing DSM are also not clear for the supply side; power generators consider it as simply a loss of profit due to power sale reduction (Yu, 2012). Thus, demand response management is mainly an administrative measure rather than a market-based approach to load management (Shen et al., 2012).

5.3 Coordination of power system planning

The above concerns reflect two fundamental challenges in wind power integration: the lack of strategic planning of China's power system as a whole and the lack of clear pricing signals to provide appropriate initiatives for different stakeholders. The former might seem paradoxical, given that China has the reputation of being a centralized society and the power system in China is tightly controlled by the central government; it reflects, among other things, the stalled reform of the Chinese power system. The lack of clear pricing signals is also in large part a product of the incomplete reform of China's power system in the early 2000s. The following subsections will elaborate on these two challenges.

5.3.1 The strategic planning of China's power system

China has a long history of guiding economic growth with central planning. Development plans have been commissioned for the national economy and specific industries since 1953. The timescale for these development plans is usually five years, and they are generally known as 'Five Year Plans'. The power industry, given its vital position in the economy, has its own Five Year Plan. For the most recent (Twelfth) five year period (between 2011 and 2015), a number of Five Year Plans for different power generation sources were commissioned, such as the *Twelfth Five Year Wind Power Development Plan*, the *Twelfth Five Year Solar Power Development Plan*, and the *Twelfth Five Year Hydropower Development Plan*. There are also other development plans that have a longer timescale, such as the *Medium–Long Term Development Plan for Renewable Energy* and the *Medium–Long Term Development Plan for Nuclear Power*; both propose the development path up to 2020.

Despite the existence of several development plans, there are several unaddressed issues related to overall strategic planning.

First, there is no integrated planning for the power system. The focus instead is on particular generation sources. While such a focus is certainly important when the priority is to satisfy the rapid growth of power demand, it is arguably even more important to have a holistic view of the power system. An integrated plan can provide answers to questions like: how much electricity is needed at what locations (power demand); how much can be supplied by what source from where (power supply); and how to deliver power from the sources of supply to the centres of demand (transmission and distribution). The existing planning of power sources is mainly focused on supply and on setting a development target for the plan period. An integrated plan would integrate supply, demand, and grid development (which is particularly important in China due to the distances between the locations of power sources and the locations of demand centres).

In addition to the lack of integrated planning of the power system, there is also a lack of strategic planning in relation to grid infrastructure (which is of course especially relevant to wind power development because, unlike conventional power sources, wind cannot be physically transported and must rely on power transmission). Given the monopoly power of China's two major power grid companies, development plans proposed by the grid companies are then approved by the NEA. A further complication is the current debate on UHV transmission systems; this is a major obstacle to the delivery of an overall grid development plan as there is as yet no agreement on whether UHV alternating current (AC) should be adopted (CEC, 2013).

Market domination by powerful grid companies is, of course, a common problem; electricity grids exhibit constant returns to scale (usually referred to as 'natural monopoly') and it is in any event undesirable to duplicate them for environmental reasons. Thus regulation is important to ensure that the market power of the incumbent companies does not result in abuse. Previously, the State Electricity Regulatory Commission (SERC) was the main body regulating the electricity market in China. In 2013, the SERC was integrated into the NEA, the body that is now responsible for energy system planning, supervision, and regulation.[16] However, there are no clear guidelines on the penalties for violations of the regulations. For example, the NEA (2014b) investigated renewable energy in Gansu. It revealed that the grid company had required renewable energy developers to provide a written commitment to take responsibility for economic losses due to curtailment, violating the *Renewable Energy Law* Article 14. However, no penalty was issued for the violation, according to the report.

Second, existing development plans provide little guidance in practice. For example, the *Medium–Long Term Development Plan for Renewable Energy* in 2007 proposed targets for wind power capacity of 5 GW by 2010 and 30 GW by 2020. However, by the year the plan was announced, wind power capacity had already reached 5.8 GW. Furthermore, the target for solar power capacity in 2015 was adjusted three times between 2012 and 2013, from 15 GW to 21 GW and finally to 35 GW (NEA, 2013b). In other words, power system planners can be rapidly overtaken by events, making it difficult to develop a long-term vision for the growth of renewable energy. This presents a significant challenge for the planning of power grids, given the uneven distribution of renewable energy sources in China. It also raises the question of how far the planning should be indicative or obligatory. In a regulated power system where prices are well designed and markets exist, a more light-handed approach to planning might be called for. But, in the absence of efficient price signals, grid networks might need to be subject to more detailed control from the centre, given their vital position in linking different parts of the power system together.

Furthermore, government policy addresses only the issue of installed capacity as the measure of renewables development. In practice, without proper system integration, installed capacity is only an indicator of wind turbine deployment, and has limited correlation with the effective use of wind power or the actual operation of wind turbines.

Third, the treatment of different regions in energy-related policy is not consistent. For example, the *Medium–Long Term Power Generation and Power Demand Projection* classifies China into four regions, according to the location and the level of economic development. The Projection provides an overview of the future growth of power demand in China's regions. At the same time, however, China is classified into six regions according to the boundaries of the regional power grids. Regional power grids are responsible for grid planning, construction, and operation within a region. Taking Inner Mongolia as an example: according to the power grid classification it is separated into East Inner Mongolia, which is part of the north-east China grid, and West Inner Mongolia which is the only provincial power grid in China. The Demand Projection classifies Inner Mongolia as part of the west region. The inconsistency between demand projection and grid planning may result in difficulties in power system planning.

Coordination is important

According to the IEA (2014), variable renewable energy (such as wind power and solar power) could account for 45 per cent of total power generation without significantly increasing power system costs

[16] The integration of the two bodies stemmed from a wish to rationalize their overlapping responsibilities in such matters as electricity system reform, project licensing, investment appraisal, and so on.

in the long run, but only under the condition of sufficient supply of back-up capacities and power storage facilities, and the implementation of demand side management. It is vital to consider wind power as a part of the larger power system rather than as a stand-alone power generation source.

The experience of the European countries in building integrated power systems within a liberalized framework might be one useful guide for coordinated power system development in China. While Europe's electricity system was historically decentralized, the Commission has been encouraging the development of a single energy market, underpinned by extensive technical analysis and the development of codes of practice. In addition, a number of reports are published to guide overall integration. For example, the so-called Ten Year Network Development Plan (TYNDP)[17] integrates the projection of power demand with planning of power supply and development of grid infrastructure and provides a long-term development plan across the EU. The TYNDP is published by the European Network of Transmission System Operators for Electricity (ENTSO-E), which represents 41 Transmission System Operators (TSO) from 34 countries. The objectives of the TYNDP are to 'ensure transparency regarding the electricity transmission network and to support decision-making processes at the regional and European level' (ENTSO-E, 2014, 17). The first pilot TYNDP was published in June 2010; it was then updated in 2012 and 2014, with improved study tools and process. The TYNDP 2014 also includes a series of six regional investment plans and a Scenario Outlook and Adequacy Forecast for the period between 2014 and 2030.

5.3.2 Market-based mechanisms

For the past few decades, the operation of China's power system has been based on administrative mandates. For instance, power pricing – from power generation, transmission, and distribution to power sales – is subject to price setting by the price department of the NDRC; electricity dispatch is based on the equal share dispatch system, under which the operating hours for similar generators in a region are almost identical.

The administrative mechanisms stand in contradiction to the aim of the power system reform initiated in 2002. The reform aimed at creating a market-based power system through the unbundling of power generation and power grids, the separation of secondary activities, the unbundling of transmission and distribution, and the creation of a competitive wholesale pricing and dispatch system.[18] Over a decade after the reform was commissioned, the only objective to have been fulfilled is the unbundling of power generation and the power grid.

The benefit of using administrative mandates is that they have provided certainty, in particular by allowing for a guaranteed return to power producers. This helped the rapid growth of total power generation capacity over recent years – from 363 GW in 2003 to 1,100 GW in 2011 (EIA, 2014). However, the approach does not provide sufficient incentives for power producers to minimize their costs and improve their efficiency (Kahrl et al., 2013). In addition, the price setting for transmission and distribution does not give clear signals about the real cost of transmission and distribution in China. (Other, more market-friendly approaches to producing a guaranteed return to power producers are, of course, possible. For instance, the UK Electricity Market Reforms are designed to offer long-term revenue security for low-carbon generation via feed-in tariffs based on Contracts for Difference (CfD) with the market price.)

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[17] For details of the TYNDP see the ENTSO-E website: https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2014/Pages/default.aspx.

[18] China's electricity system has experienced major reforms, which began in the late 1990s. The Ministry of Power was abolished in 1998, in order to separate management and operation of the electricity industry. Previously, the Ministry of Power had been in charge of power system investment, planning, and surveillance. The State Power Corporation was set up with responsibility for power system operation from 1998. The Corporation was further separated into five power generation companies and two power grid companies in 2002. For more details of the reform, refer to (IEA, 2006) and (Ma and He, 2008).

Simulations show that China could benefit from a market-based power system, through improvements in energy efficiency, growth in employment, and optimal capacity expansion (Chen and He, 2013,Gao and Van Biesebroeck, 2014). A market-based approach could also promote the integration of wind power by providing:

1. clear price signals for the deployment of wind turbines at different locations (for example, is it is more cost effective to build wind farms at remote inland locations or to build offshore wind farms nearer the demand centres?);
2. clear price signals for the participation of conventional power plants in ancillary services, which is required due to wind power intermittency;
3. economic incentives to end users to manage their power demand (the application of DSM); and
4. signals for the rational development of the transmission system.
5. Of course, as long as wind power remains more expensive than other sources, this extra cost would have to be reflected in higher prices (or taxes) or in some other way, but the hope is that in the longer run, spurred on by technological development, wind costs overall would fall to a fully competitive level.

Although power system deregulation would bring a number of benefits to China's power system, it is believed that the government has no intention of fully deregulating power pricing in the near future. The main concern is that deregulation would result in a significant increase in end-use prices, which could cause social instability in China (Ma, 2011). However, a deregulated power system does not need to be built in one day. A gradual approach could help move the system in the direction of greater efficiency. Meanwhile, the slowdown in the growth of electricity demand may make it easier to introduce institutional and market changes, since it reduces the pressure to focus solely on getting new generation capacity built.

Thus, although the growth of wind power capacity since the 2000s is significant, there are still concerns relating to the development of China's transmission system and the economics of wind power integration, which could impede the future growth of wind power in China. Strengthening the strategic planning of China's power system and providing clear pricing signals could be helpful in addressing these concerns.

6. Conclusion

China has experienced significant growth in wind capacity in the past decade. Total installed capacity increased from 346 MW in 2000 to 91,413 MW in 2013. Significant wind power potential, favourable government policies, and the development of domestic wind manufacturing capacity all contributed to this growth. However, the system as a whole has not fully absorbed the growth in wind capacity. For instance, there are significant levels of wind curtailment, especially in the wind-rich regions. The curtailments result from rapid capacity growth in wind-abundant regions, insufficient local demand, insufficient transmission capacity, and a lack of flexibility in the power system. Although several transmission routes are planned to link the wind-rich regions to the demand centres, it is not clear whether these planned routes are sufficient to accommodate the future growth of wind power. In addition, transmission pricing is too opaque to clearly reflect the real costs of power transmission. Furthermore, the renewable energy fund that is used to subsidize wind power has significant and growing deficits. All these challenges are likely to become more acute with the projected growth of wind power and may provide serious obstacles to its effective and efficient integration into the overall electricity system.

These problems appear to stem from the lack of strategic planning of the entire power system, along with the lack of clear price signals to guide the development of wind power. Both in order to promote effective integrated development of the power system and, more specifically, in order to accommodate the growth of wind power, the government should consider ways of improving policy coordination and the strategic planning of electricity development, and of increasing the use of market-based measures – rather than relying on administrative mandates to guide the decisions of individual producers, consumers, and grid operators.

7. References

Bird, L., Cochran, J., & Wang, X. (2014). 'Wind and Solar Energy Curtailment: Experience and Practices in the United States', National Renewable Energy Laboratory.

Bundesnetzagentur (2014). 'Monitoring Report 2013', Bonn: Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen.

CEC (2013). 'UHV projects approval is impeded when the Twelfth Five Year Plan on power grid development will be issued', (特高压项目评估受阻 十二五电网规划何时出台), China Electricity Council. Available online: http://www.cec.org.cn/xinwenpingxi/2013-12-31/114707.html [Accessed 4 November 2014.]

Chen, S. & He, L. (2013). 'Deregulation or Governmental Intervention? A Counterfactual Perspective on China's Electricity Market Reform', *China & World Economy*, 21**,** 101–20.

CNKI (2014). 'Provincial power industry development', China National Knowledge Infrastructure, Beijing.

CWEA (2013). 'Statistics on China's wind power installed capacity in 2012', (2012 年中国风电装机容量统计）, Beijing: Chinese Wind Energy Association.

CWEA (2014). 'China wind power installed capacity in 2013', (2013 年中国风电装机容量统计）, Beijing: Chinese Wind Energy Association.

Daubney, K. (2013). 'Wind curtailments fall dramatically', *Wind Power Monthly*, available online: http://www.windpowermonthly.com/article/1185979/uk-wind-curtailments-fall-dramatically [Accessed 2nd December 2014.]

Davidson, M. (2014). 'Institutional & Technical Analysis of Wind Integration Challenges in Northeast China', Tsinghua–MIT, China Energy & Climate Project, Beijing.

EIA (2014). International Energy Statistics, US Energy Information Administration, http://www.eia.gov/countries/data.cfm.

Ellermann, C. & Böning, C. (2014). 'China starts trading carbon', *Oxford Energy Forum*, Issue 95, February 2014.

ENTSO-E. (2014). '10-Year Network Development Plan 2014', European Network of Transmission System Operators for Electricity, available at: https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202014/141031%20TYNDP%202014.pdf. [Accessed 10 December 2014.]

Feng, K., Hubacek, K., Siu, Y. L. & Li, X. (2014). 'The energy and water nexus in Chinese electricity production: A hybrid life cycle analysis', *Renewable and Sustainable Energy Reviews*, 39**,** 342–55.

Gao, H. & Van Biesebroeck, J. (2014). 'Effects of Deregulation and Vertical Unbundling on the Performance of China's Electricity Generation Sector', *The Journal of Industrial Economics*, 62**,** 41–76.

Han, G., Olsson, M., Hallding, K. & Lunsford, D. (2012). *China's Carbon Emission Trading – An Overview of Current Development*, Stockholm, Sweden: SEI/FORES.

Hu, Z., Moskovitz, D. & Zhao, J. (2005). *Demand-Side Management in China's Restructured Power Industry: How Regulation and Policy Can Deliver Demand-Side Management Benefits to a Growing Economy and a Changing Power System*, Washington DC: World Bank.

IEA (2006). *China's Power Sector Reforms: Where to Next?*, Paris: International Energy Agency.

IEA (2014). *The Power of Transformation – Wind, Sun and the Economics of Flexible Power Systems*, Paris: International Energy Agency.

IEA/NDRC (2011). *Technology Roadmap: China Wind Energy Development Roadmap 2050*, Paris/Beijing.

Kahrl, F., Williams, J. H. & Hu, J. (2013). 'The political economy of electricity dispatch reform in China', *Energy Policy*, 53**,** 361–69.

Lema, A. & Ruby, K. (2006). 'Towards a policy model for climate change mitigation: China's experience with wind power development and lessons for developing countries', *Energy for Sustainable Development*, 10**,** 5–13.

Lewis, J. I. (2014). 'Managing intellectual property rights in cross-border clean energy collaboration: The case of the U.S.–China Clean Energy Research Center', *Energy Policy,* 69**,** 546–54.

Li, J., Cai, F., Qiao, L., Wang, J., Gao, H., Tang, W., Peng, P., Geng, D., Li, X. & Li, Q. (2014a). '2014 China Wind Power Review and Outlook', (中国风电发展报告）, CREIA/CWEA/GWEC.

Li, J., Shi, J., Xie, H., Song, Y. & Shi, P. (2006). 'A Study on the Pricing Policy of Wind Power in China', China Renewable Energy Industries Association, Greenpeace, and Global Wind Energy Council.

Li, J., Shi, P. & Gao, H. (2010). *China Wind Power Outlook 2010*, Haikou: Hainan Press.

Li, J., Yang, X. & Zhang, M. (2014b). 'Addressing climate change: China's status and policies', *Oxford Energy Forum*, February 2014, 95**,** 22–5.

Li, J. F. & Gao, H. (2007). *China Wind Power Report 2007*, Beijing, China: Environment Science Press.

Li, J. F., Gao, H., Wang, Z. Y., Ma, L. J. & Dong, L. Y. (2008). *China Wind Power Report 2008*, Beijing: China Environment Science Press.

Liu, Y. & Kokko, A. (2010). 'Wind power in China: Policy and development challenges', *Energy Policy*, 38**,** 5520–9.

Ma, C. & He, L. (2008). 'From state monopoly to renewable portfolio: Restructuring China's electric utility', *Energy Policy*, 36**,** 1697–711.

Ma, J. (2011). 'On-grid electricity tariffs in China: Development, reform and prospects', *Energy Policy,* 39**,** 2633–45.

Mathews, J. & Tan, H. (2014). 'Economics: Manufacture renewables to build energy security', *Nature*, 513, 10 September.

McElroy, M. B., Lu, X., Nielsen, C. P. & Wang, Y. (2009). 'Potential for Wind-Generated Electricity in China', *Science*, 325**,** 1378–80.

MEP 2013. (2013). 'The Implementation Rules of the Air Pollution Prevention and Control Action Plan in Beijing–Tianjin–Hebei and Surrounding Regions', (京津冀及周边地区重点行业大气污染限期治理方案）, Ministry of Environmental Protection, Beijing.

MEP. (2014). 'Zhang Gaoli attends UN Climate Summit and makes an address', Ministry of Environmental Protection, Beijing. Available: http://english.mep.gov.cn/News_service/infocus/201409/t20140929_289714.htm. [Accessed 12 November 2014.]

Moura, P. S. & de Almeida, A. T. (2010). 'The role of demand-side management in the grid integration of wind power', *Applied Energy*, 87**,** 2581–8.

Müller, B., Robinson, D. & Zhang, X. L. (2010). 'Addressing Large Developing Country Emissions: The case for strategic Sino-European Collaboration under joint commitments', Working Paper EV 53, Oxford Institute for Energy Studies, June.

NBS. (2014). 'The national economy experienced a steady growth in 2013', (2013 年国民经济发展稳中向好), Beijing: National Bureau of Statistics. Available: http://www.stats.gov.cn/tjsj/zxfb/201401/t20140120_502082.html [Accessed 2nd December 2014].

NDRC (2007). 'Mid–Long Term Development Plan for Renewable Energy in China', National Development and Reform Commission, Beijing.

NDRC (2014). 'Energy Saving and Emission Reduction Planning on the Advancement and Upgrade of Coal Power Plants (2014 - 2020)', (煤电节能减排升级与改造行动计划（2014–20 年）, National Development and Reform Commission, Beijing.

NEA. (2013a). 'Medium–Long Term Projections on Power Supply and Demand in China', (我国中长期发电能力及电力需求发展预测), National Energy Administration, Beijing. Available online: http://www.nea.gov.cn/2013-02/20/c_132180424.htm. [Accessed 4 November 2014.]

NEA. (2013b). 'NEA adjusts the target for solar power installed capacity', (能源局再度上调太阳能发电装机容量), National Energy Administration, Beijing. Available online: http://jsb.nea.gov.cn/news/2013-1/201313194832.htm. [Accessed 4 November 2014.]

NEA. (2014a). 'National power generation capacity increased rapidly in 2013', (2013 年全国发电装机平稳较快增长、结构持续优化), National Energy Agency, Beijing. Available online: http://www.nea.gov.cn/2014-02/10/c_133103837.htm. [Accessed 2nd December 2014]

NEA (2014b). 'Renewable Energy Generation and Integration: a report on Gansu province', (可再生能源发电并网驻点甘肃监管报告）, National Energy Administration, Beijing.

PeopleNet (2014). 'Higher Dependence on Imported Coal, Oil and Natural Gas in China', (煤油气对外依存度高企 去年煤炭进口量创新高), available online: http://energy.people.com.cn/n/2014/0124/c71890-24212885.html. [Accessed 4 November 2014.]

Pu, J. (2012). 'The difficulty in renewable energy fund', (8 厘钱的困境）, *CaixinOnline*, Beijing. Available online: http://magazine.caixin.com/2012-12-28/100478063.html. [Accessed 4 November 2014.]

Reuters. (2014). 'China pledges to reduce CO_2 emission per unit of GDP by 40–45% in 2020', (中国提出 2020 年单位 GDP 二氧化碳排放下降 40%–45%）, *Reuters*, Beijing. Available online: http://cn.reuters.com/article/CNEnvNews/idCNKBS0HE0E820140919 [Accessed 4 November 2014.]

SERC (2007). 'Provisional Measures on Transmission and Distribution Price Setting', (跨区域输电价格审核暂行规定), State Electricity Regulatory Commission, Beijing.

SGCC (2014). 'Report on SGCC Electricity Trade 2013', (国家电网公司 2013 年度电力市场交易信息报告), State Grid Corporation of China, Beijing.

Shen, B., Ni, C. C., Ghatikar, G. & Price, L. (2012). 'What China Can Learn from International Experiences in Developing a Demand Response Program', Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, June.

Shi, P. (2007). 'China wind power generation capacity in 2006', China Wind Energy Association, Beijing.

Stanway, D. 2014. 'China, US agree limits on emissions, but experts see little new', *Reuters*, Beijing. Available online: http://www.reuters.com/article/2014/11/12/us-china-usa-climatechange-idUSKCN0IW07Z20141112. [Accessed 12 November 2014.]

State Council (2012). 'The 12th Five Year Plan on Energy Saving and Emission Reduction', (节能减排"十二五"规划), The State Council, Beijing.

State Council (2013a). 'Air Pollution Prevention and Control Action Plan', (大气污染防治行动计划）, The State Council, Beijing.

State Council (2013b). 'Twelfth Five Year Plan for Energy Development', (十二五能源发展规划), The State Council, Beijing.

Xiao, Q. (2014) 'Could the curtailment be reduced? Not really', (弃风限电好转？未必！), *China Energy Newspaper* (中国能源报), available online: http://paper.people.com.cn/zgnyb/html/2014-11/03/content_1495756.htm. [Accessed 12 November 2014.]

Xinhua (2013). '*Renewable energy subsidies are expected to double (可再生能源电价附加有望翻番最快7月出台)*'. *Xinhuanet*. Available online: http://news.xinhuanet.com/energy/2013-06/26/c_124911691.htm [Accessed 10 December 2014].

Xinhua (2014) 'Li Keqiang's speech at Summer Davos opening ceremony – full text', *Xinhuanet*, 10 September Tianjin, available online: http://news.xinhuanet.com/english/china/2014-09/11/c_126972756.htm. [Accessed 8 December 2014.]

Yang, M., Patiño-Echeverri, D. & Yang, F. (2012). 'Wind power generation in China: Understanding the mismatch between capacity and generation', *Renewable Energy*, 41**,** 145–51.

Yu, N. 2014. *Twelve years into the electricity reform does not make the transmission and distribution price clear? (电改十二年为何理不清输配电价？)*. Available online: http://companies.caixin.com/2014-11-06/100747670.html. [Accessed 12 November 2014].

Yu, Y. (2012). 'How to fit demand side management (DSM) into current Chinese electricity system reform?', *Energy Economics*, 34**,** 549–57.

Zhao, X., Zhang, S., Zou, Y. & Yao, J. (2013). 'To what extent does wind power deployment affect vested interests? A case study of the Northeast China Grid', *Energy Policy*, 63**,** 814–22.

Zhao, Z. Y., Hu, J. & Zuo, J. (2009). 'Performance of wind power industry development in China: A Diamond Model study', *Renewable Energy*, 34**,** 2883–91.