

Onshore wind power development in China: Challenges behind a successful story

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ARTICLE INFO

Article history:

Received 17 November 2008

Accepted 10 March 2009

Available online 1 May 2009

Keywords:

China

Onshore wind power

Project performance

ABSTRACT

Wind energy utilization, especially onshore grid-connected wind power generation, has a history of 30 years in China. With the increasing attention to renewable energy development in recent years, wind energy has become the focus of academic research and policy-making. While the potential and advantages of wind energy are widely recognized, many questions regarding the effectiveness of policies and performances of current practices remain unanswered. This paper takes Inner Mongolia, the province that has the most abundant wind energy resources in China, as a case to assess the performance of Chinese onshore wind power projects, focusing on the institutional setting, economic and technological performance, as well as environmental and social impacts. Results show that China is experiencing a rapid growth in wind power generation, which brings China great environmental, energy security and social benefits. However, for a full development of wind energy in China a number of barriers need to be removed: high generation cost, low on-grid price, and stagnating development of domestic manufacture. These findings lead to three policy recommendations.

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1. Introduction

Wind energy is a pollution-free, infinite sustainable form of energy. Utilization of wind energy uses no natural resource and generates no greenhouse gas or toxic waste. Modern wind power technologies can convert the kinetic energy present in wind into a more useful form—electric power. Existing wind power technologies fall into three categories: grid-connected wind farms, distributed generation, and off-grid standalone system. All categories can be installed both onshore and offshore. The onshore grid-connected wind farm – subject of this paper – is the most mature and widely used technology in the world, and so is it in China.

With its large land mass and long coastline, China is rich in wind energy resources. Estimation by China Meteorological Administration showed that an average wind power density in China is about 100 W/m², with 253 GW of exploitable onshore wind resource (measured at relatively low height of 10 m above ground) and 750 GW of exploitable offshore wind resource (Li et al., 2005). Another research, carried out by the UNEP in cooperation with the US National Renewable Energy Laboratory (NREL), calculated 1400 GW (at 50 m height) of exploitable

onshore wind resource and 600 GW of exploitable offshore wind resource (Li et al., 2007; Yang, 2004).

China's efforts to develop wind power can be traced back to the early 1970s. Since then, especially in the past 20 years, the national government has initiated a set of nation-level projects to increase the production and consumption of wind electricity. As a result, total installed capacity in China increased from 25 MW at the end of 1996 to 5906 MW at the end of 2007. About 160 wind farms at different scales have been established on the Qinghai-Tibet Plateau, Inner Mongolia, the North-West Region, and the South-East Coastal Region of China.

Grid-connected wind power is well developed in Inner Mongolia, especially after 2005. By the end of 2007, its wind power generation capacity exceeded 1000 MW. Given its great potential for wind energy development, Inner Mongolia is considered a priority area to develop wind power by both national and local governments, therefore more wind farms will be built in this area in the future. The government aims to increase the total wind power capacity in Inner Mongolia to reach 4000 MW by 2010. This makes Inner Mongolia a perfect case to examine wind energy development in China.

Against the above-mentioned background, this paper aims to investigate the constraints for the development of wind energy production to suggest policy recommendations related to that. First, an overview of wind power development in Inner Mongolia is presented. Subsequently, wind power projects in Inner Mongolia are evaluated regarding their institutional setting,

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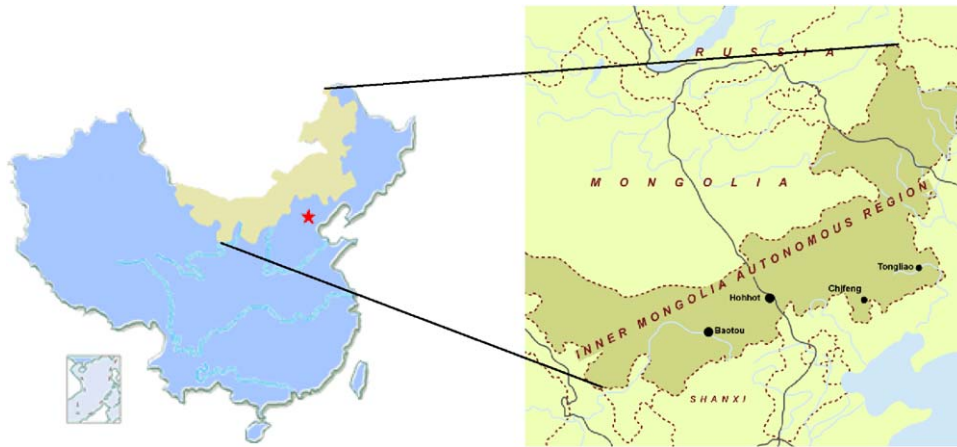


Fig. 1. Map of China with highlighted Inner Mongolia.

economic and technological performance, and environmental and social impacts. Finally, following this evaluation policy suggestions are formulated for improving wind power development in China.

2. Wind power development in Inner Mongolia

2.1. Rich wind energy resources

Inner Mongolia, China's northern border autonomous region, features a long, narrow strip of land sloping from northeast to southwest, neighboring Mongolia and Russia in the north (Fig. 1). It stretches 2400 km from west to east and 1700 km from north to south. It is the third largest province in China, covering an area of 1.18 million km², or 12.3% of the country's territory. It is sparsely populated, with only 24.05 million inhabitants (data at the end of 2007). Inner Mongolia has plateau landforms, mostly more than 1000 m above sea level. Besides 86.67 million hectares of grassland, there are also hills, plains, deserts, rivers, and lakes in Inner Mongolia. It is mainly characterized by temperate zone continental monsoon climate with yearly average temperatures of 0–8 °C and yearly temperature differences of 35–36 °C. Spring is warm and windy; summer is short and hot with many rainy days; autumn usually sees early frost and dropping temperatures; winter is long and bitter cold.

Inner Mongolia is abundant in wind energy resources due to its special geographic characteristics such as relative high altitude, open terrain, low vegetation, few buildings, speed increasing effect when north-south air flows through the raised landform, and small ground friction. According to estimations by China Meteorological Administration, Inner Mongolia has 101 GW of exploitable onshore wind energy resources, 40% of the nation's total amount. Furthermore, wind energy resource in Inner Mongolia is distributed evenly both at spatial and temporal scales. Four-fifths of its vast territory is suitable for developing wind power, with minimally 4400 and maximally 7800 h of effective wind speed (5–25 m/s) accumulation (Table 1). In one word, Inner Mongolia is a perfect place for developing wind energy.

2.2. History of wind power development

Only in the 1970s, Inner Mongolia started to develop wind power by constructing off-grid standalone wind turbines for herdsmen. The first grid-connected wind farm in Inner Mongolia

was built in December 1989. At that time, five 100 kW wind turbines (Model 56) produced by the American company Wind Power were installed in Zhurihe Wind Farm, in the north-central part of Inner Mongolia. Subsequently, four other wind farms were constructed in succession: Shangdu in 1994, Xilinhot in 1995, Huitengxile in 1996, and Dali in 1999. At this stage, scales of wind farms were very limited, with maximum individual turbine capacity of 600 kW and wind farm capacity of 5400 kW (in Huitengxile). There existed no domestic wind turbine manufacturer. All equipments were imported from Spain, United States, Denmark, and Germany.

Wind power developed steadily from 2000 to 2005 in Inner Mongolia, with an annual increase of 16% in installed turbines and 24% in installed capacity (see Figs. 2 and 3). At this stage, a market of domestically produced wind power equipment emerged, symbolized by the establishment and growth of domestic wind turbine manufacturers. Although the proportion of domestically manufactured installed capacity in total installed capacity reached only 15% in 2005, China became one of the countries capable of manufacturing wind turbines independently.

Development of wind power in Inner Mongolia skyrocketed in 2006 and 2007, during which period most of the wind farms in Inner Mongolia were constructed. Installed wind power capacity tripled in both years and so did the number of installed wind turbines (Figs. 2 and 3). At the end of 2006, Inner Mongolia exceeded Xinjiang to become the leading province in installed wind power capacity in China. By the end of 2007, Inner Mongolia had 33 wind farms (at 19 locations) with 1856 wind turbines and 1683.69 MW of installed capacity, which accounted for 26.5% of the total installed capacity in China (Table 2). At this stage, domestic manufacturing capability and capacity also increased rapidly. The proportion of domestically produced turbines in the total installed capacity increased to about 60% by the end of 2007. This proved to be vital for lowering the cost of wind turbines and of constructing wind farms.

2.3. Current policy objectives

From the Eighth Five-year Plan (1991–1995) until the Eleventh Five-year Plan (2006–2010), China gives the development of renewable energy resources, especially biomass, solar, small hydro and wind energies, strategic importance in every stage of its long-term national development plan.¹ *China's Renewable Energy Law*,

¹ In the *China Electric Power Act* (1995), the first Chinese law that discusses energy policy, it was declared that China government "encourages the develop-

Table 1
Wind energy resource in Inner Mongolia (Source: Zang and Feng, 1998).

	Area (10 ³ km ²)	Wind power density (W/m ²)	Wind energy density (kWh/m ²)	Effective wind speed accumulation (h)
Greatly abundant	83	240–400	1500–3600	6100–7800
Abundant	200	180–220	1000–1500	5300–6780
Exploitable	660	100–200	400–1000	4400–6000

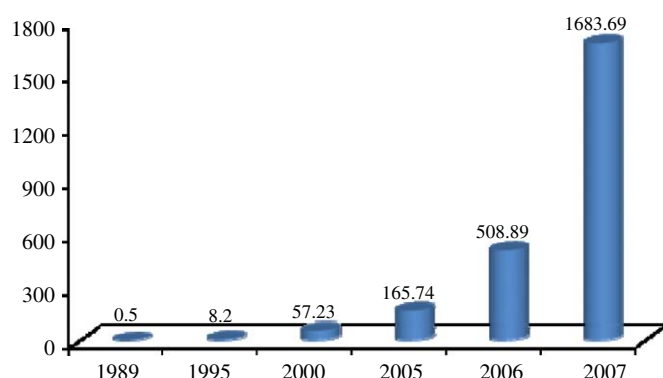


Fig. 2. Installed wind power capacity in Inner Mongolia (MW).

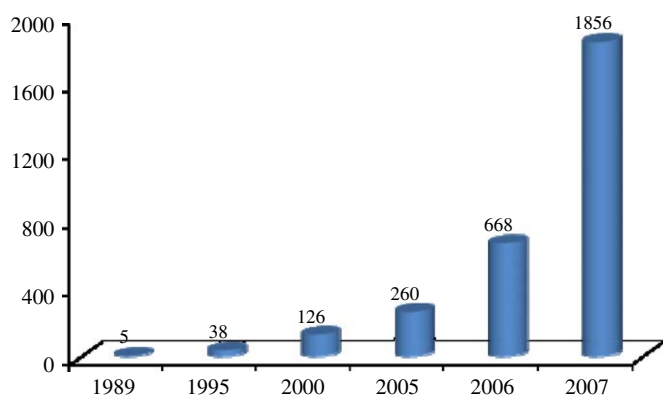


Fig. 3. Installed wind turbines in Inner Mongolia.

which was activated in 2006, set developing renewable energy as priority in national energy strategy, aiming to establish capacity and infrastructure for rapid renewable energy development, and to create a sustainable market for renewable energy. Through the law, R&D and commercialization of renewable energy technologies were regarded as priority of modern technology and high-tech industry development at national level. The Chinese government has also set compulsory market shares of wind energy for different target years. The *Mid-Long Term Plan of Renewable Energy Development* required installment of 5000 MW of onshore wind power capacity and 200 MW of offshore wind power capacity by 2010, as well as 30000 MW onshore and 1000 MW offshore by 2020. The *11th Five-Year Renewable Energy Development Plan*, passed in March 2008, doubled the 2010 onshore objective to 10000 MW. Besides these targets, in 2003 China also set targets

for a mandatory proportion of domestically produced wind turbines used in newly constructed wind farms that every turbine must meet the 70% domestic cost content requirement, in order to further develop a national wind industry and to lower the costs of wind farm construction.

In Inner Mongolia, the government has set clear development targets for wind power in its official documents²: by the end of 2010, the total installed capacity of onshore grid-connected wind power has to reach 4000 MW. It is an ambitious target, as the Inner Mongolia government aims to fulfill 80% of the 2010 national target of onshore wind power development. In order to achieve this target, in the same documents the Inner Mongolia government planned five GW-level wind farms – Huitengxile, Huitengliang, Bayinhanggai, Saihanba, and Bayinxile – to construct another 2316 MW installed capacity within 3 years. Notably, 1174.8 MW of capacity was installed in 2007. In other words, most likely Inner Mongolia will easily reach its 2010 development targets within the remaining 3 years if it continues at the current speed of wind farm development. Some experts even expressed their concerns regarding a too rapid development of wind power, and advocated sticking to the predetermined schedule.

3. Evaluation methods of wind power projects performance

After 15 years of development, wind power generation in Inner Mongolia has grown up. Nevertheless, increase in scale alone does not necessarily mean successful wind power development. Inner Mongolia still falls short in wind power production compared to a number of western countries. An integrated evaluation of the implementation performance of wind power projects in Inner Mongolia can assess the achievements in developing wind power in this autonomous region during the past years, and appraise what changes are necessary for the future.

In evaluating the performance of wind power development in Inner Mongolia, this paper focuses on a systematic analysis of wind farms in Inner Mongolia regarding four aspects: the institutional arrangements, economic performance of wind farms, technological performance of wind farms, as well as social and environmental impacts.

Data for performance evaluation were collected from three sources. First, documents from various sources were reviewed to get a clear idea what kind of policies have been formulated, what policy measures and objectives have been determined, and what outcomes have been claimed in Inner Mongolia. Different methods have been used at different stages of this research to collect official and unofficial policy documents, governmental reports and scientific publications. Second, face-to-face in-depth interviews were held with officials and experts in governmental departments (at national, provincial, and local levels), wind power

(footnote continued)

ment and utilization of new and renewable energy resources". This principle was reaffirmed in *China Energy Saving Law* (1998), *Mid-Long Term Plan of Renewable Energy Development* (2007), and the *Eleventh Five-Year Plan for New and Renewable Energy* (2008).

² The 11th Five-year Plan of Energy Industry in Inner Mongolia and the 11th Five-year Plan and 2020 Long-term Targets of Wind Power Development in Inner Mongolia, both issued by Inner Mongolia Development and Reform Commission (IMDRC) in 2006.

Table 2

List of wind farms in Inner Mongolia (Source: Shi, 2008b; adapted and updated by the authors).

Location	Wind farm	Number of turbines	Total capacity (MW)
Sonid Youqi	Zhurihe	50	33.90
Shangdu	Dashanwan	12	3.60
Xilinhot	Baoligenshan	13	4.78
Qahar Youyi	Huitengxile	214	189.00
Zhongqi	Dadonggou	120	121.50
	Dayangpuzi	134	100.50
	Caoduozi	29	44.50
Hexigeten Qi	Dali (Maolin)	73	51.36
	Dali (Datang)	27	40.50
	Saihanba	195	165.75
	Daheishan	4	3.40
	Nandian	4	3.00
Duolun	Xishan	36	30.60
Ongniud Qi	Sunjiaying	134	100.50
	Wudaogou	66	49.50
	Bolike	4	8.00
Songshan Qu	Dongshan	120	102.00
Xin Barag Youqi	Altanemole	33	49.50
Zhuozhi	Bayinxile	34	44.00
Zhengxiangbai Qi	Baoligentaohai	2	3.00
Abag Qi	Huitengliang (Beifang)	33	49.50
	Huitengliang (Guohua)	73	99.50
	Huitengliang (Datang)	38	57.00
Bayan Kuangqu	Aorigehu	2	1.50
Damao Qi	Bailingmiao	28	35.00
Erehot	Xili	4	6.00
Hanggin Qi	Yihewusu	43	32.25
Urad Houqi	Narenbaoligen	10	7.50
Urad Zhongqi	Bayinhanggai	58	43.50
	Chuanjing	124	98.80
	Turiguge (Huiren)	66	49.50
	Turiguge (Zhongdiantou)	20	15.00
Taibus Qi	Gongbaolage	53	39.75
Total	33	1856	1683.69

research institutes, and companies. Semi-structured questionnaires were used for these interviews.³ Third, representative case studies were carried out at Huitengxile, Zhurihe, and Dashanwan wind farms in Inner Mongolia. These three wind farms are different at locations, scales and main turbine manufacturers, representing all wind farms in this Inner Mongolia. On-site observations, systematic closed interviews with staffs in wind farms, and discussions with local residents and neighbors were carried out at each wind farm.

4. Institutional arrangements for wind power projects

Issues concerning institutional arrangement for wind power projects in Inner Mongolia include project approval, wind farm management and pricing policy. There are two types of wind power projects in Inner Mongolia: government contract projects

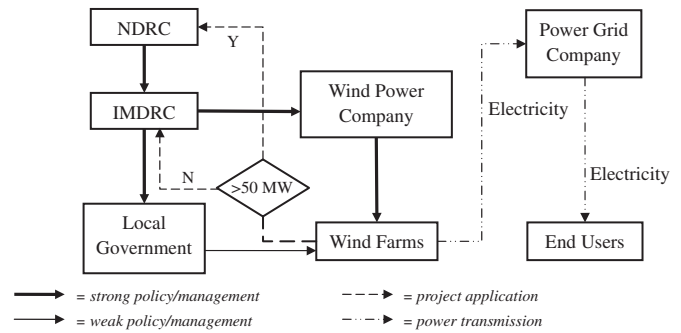


Fig. 4. Institutional structure of wind farm management in Inner Mongolia.

and concession projects. Government contract projects appeared in the early 1980s, while concession projects have a relatively shorter history, as the first project was carried out in 2003.

4.1. Government contract projects

Approval of government contract projects works as follow: wind power companies hand in project proposal to National Development and Reform Commission (NDRC) or Inner Mongolia Development and Reform Commission (IMDRC). For projects larger than 50 MW, the NDRC is responsible for decision-making; while the IMDRC, local counterpart of NDRC, can approve projects smaller than 50 MW without approval from NDRC.

Wind farms in operation are run by wind power companies that constructed the wind farms. While all wind power companies in Inner Mongolia are directly managed by IMDRC. Purchase of wind power is strictly controlled by the national government. Prices of wind electricity are decided in Power Purchasing Agreements (PPA) signed between NDRC (or IMDRC) and wind power companies by calculating generation cost and reasonable profit rate. The two power grid companies in China, the State Power Grid Corporation and the Southern Power Grid Corporation, are obliged to purchase all wind electricity, which is subsequently sold to ender users from these two grid companies. If the purchasing price of wind power is higher than the price of power generated from other sources, the price difference will be apportioned within the whole power grid (Fig. 4).

This project management mechanism has two advantages. First, there exist a legal separation between electricity generation and electricity transport and distribution. Wind power is generated by wind power companies, while it is transported and distributed by power grid companies. This separation to some extent can avoid monopolization of the wind power market. Some Chinese professionals foresee a separation of electricity transport and distribution in the near future, not unlike what we witness in several western countries. Second, the authority of IMDRC to decide on wind power projects smaller than 50 MW significantly increases efficiency of wind farm establishment. At the early stage of wind power development in China, every new project needed to be approved by NDRC, which made the application for wind power projects very complex and time consuming. This new project approval procedure gives impetus to the rapid development of wind farms in Inner Mongolia.

4.2. Concession projects

In addition to government contract projects, a new and special wind power project model, called the "concession model" (Fig. 5), is increasingly used for wind power projects in China (Lema and

³ Interviews were held at: Center for Renewable Energy Development in Energy Research Institute NDRC; Department of Energy IMDRC; Department of Electricity of Wulanchabu City, Inner Mongolia; Inner Mongolia Association for Science and Technology; Government of Qahar Youyi Zhongqi, Wulanchabu City, Inner Mongolia; Chinese Wind Energy Association; Research Institute for Wind Power, Inner Mongolia; Inner Mongolia North Longyuan Wind Power Company Ltd.

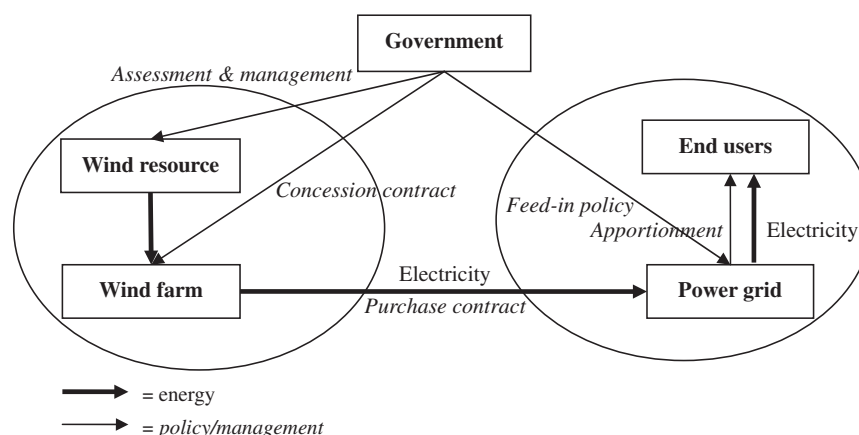


Fig. 5. Concession model of wind power development (Source: adapted from Zhou and Han, 2005).

Ruby, 2007). Before 2003, the development of a wind power project was granted to one consortium under a government contract. In 2003, the concession model was effectuated to stimulate competition in wind power development. Essentially, the concession model is a tender system. The China Meteorological Administration assesses wind resources throughout the country. NDRC offers several selected locations for concession projects to power companies who are interested in generating electricity from wind energy, and provides investment facilities like the establishment of access roads and power grid. Wind energy developers – usually power companies combined with a wind turbine manufacturer – are invited to bid for the development of a location. The one who offers the best price per kWh on the terms provided will win the concession and thus the right to produce electricity on the site.⁴ In December 2007, the fifth concession bid was opened in Inner Mongolia.

The pricing of wind electricity under concession projects works as follows: during the first 30000 full load hours, wind farms sell wind electricity to the grids at the price pre-established in the original bid. After this initial period and until the end of the concession period, electricity is sold at a uniform on-grid price. The wind electricity is purchased in the same way as from government contract projects.

Advantages of this concession model include the combination of functions of government and power companies, the selection of suitable developers and lower wind power prices. All power companies are allowed to participate in wind power development by bidding for and putting financial resources into concession projects. By the end of 2007, totally 1600 MW of wind power projects have been approved through the concession model in Inner Mongolia.

However, the concession model has also obvious disadvantages. First, some bidders intentionally underestimate operating costs to get a lower power price compared to other bidders. Once the bid is selected, it proves economically impossible to construct and operate the wind farm. In other words, insufficient financial resources are put into the development of the wind farm. Large power companies in China are required to build a certain amount of generation capacity from renewable energy resources.⁵ This is

an important reason for hiding costs of wind power in other investments to win the bid. Lacking competition of international developers or turbine manufacturers in the concession bids is another reason for this problem. This problem has been partly solved in the fifth phase of concession projects, which changed the bid and selection mechanism in the following way: the highest bid and lowest bid were excluded and then the bid most close to the average price of the remaining bids won the concession project.

Second, the concession model may reduce government's normal tax income. Under the concession model, wind power developing enterprises who win the concession bids enjoy preferential tax policy. There is a great chance that the enterprises include other economic activities into wind power projects so that they can gain more economic profits with low tax rates. Without effective monitoring, the government's revenue is possible to be hurt.

5. Economic evaluation of wind power projects

5.1. Funds for wind power project development

The most crucial task in wind power development is ensuring funding. Currently, the average construction cost of wind farms is about 10000 yuan/kW. This means Inner Mongolia needs some 23.16 billion yuan over the year 2008–2010 to fulfill its development objectives. Funds for wind farm construction were initially raised mainly by the national government from Chinese banks and international cooperation projects. For instance, 50 million US dollars of mixed credit⁶ was provided by the Danish Government to construct the Huitengxile Wind Farm in 1996. A similar funding channel was used to develop the Zhurihe Wind Farm and the Dahanwan Wind Farm. With this mechanism, allocation and utilization of funds were strictly monitored by governmental departments, and financial security and transparency was ensured.

With the rapid development of wind power in Inner Mongolia (and in China), international financial resources could no longer meet the need of wind farms developers. In order to overcome this

⁴ From the second bid, the so-called "equipment localization rate" was also brought into the decision of selecting the developer. This refers to the degree to which the developer uses domestically produced equipment and technology.

⁵ In the *Mid-Long Term Plan of Renewable Energy Development*, NDRC announced Renewable Portfolio Standard (RPS) mandates in power generation sector. For the whole sector, the share of electricity generated from non-hydro renewable energy resources should reach 1% of total electricity generation by 2010

(footnote continued)

and 3% by 2020. For any power producer with installed capacity greater than 5 GW, the mandatory share is raised to 3% by 2010 and 8% by 2020.

⁶ Mixed credit is an interest free or low interest loan with 10 or 15 years maturity aimed at financing supplies of equipment and related services for development projects in relatively creditworthy developing countries.

barrier, two additional mechanisms were introduced. First, the Clean Development Mechanism (CDM) provided a major channel for foreign funding (Gilau et al., 2007). In 2002, the first CDM contract between the Netherlands and China was signed. According to this contract, the Netherlands buys Carbon Emission Reduction credits (CERs) from China through the Huitengxile Wind Farm project at a price of 54 yuan/t of CO₂ reduction. Within the 10-year contract period, 54000 t of CO₂ emission would be reduced, which provided Huitengxile 0.27 billion yuan of Dutch funding. Second, the wind power concession model has advantages in attracting investments from power companies. Inner Mongolia used the funds raised through the concession model to scale up its wind power development. The Huitengxile Wind Farm was extended (200 MW) by the second concession bid. The Huitengliang Wind Farm (300 MW × 2) and Bayinxile Wind Farm (200 MW) were approved by the fourth concession bid (Li et al., 2007). The Nialan Yiligeng Wind Farm (300 MW) and Tongliao Beiqinghe Wind Farm (300 MW) were approved by the fifth concession bid (Ni, 2008).

5.2. Poor economic profits

To compete with conventional energy resources, it is important for wind farms to gain enough profit during operation. Unfortunately, wind farms in Inner Mongolia are not yet able to achieve satisfying profits, mainly due to both high generation costs and cheap prices of wind power.

Firstly, the cost of wind power is higher than that of fossil fuel electricity in Inner Mongolia. Average costs for wind electricity generation in Inner Mongolia range between 0.45 and 0.60 yuan/kWh. Meanwhile, the average cost of coal-fired electricity is only 0.30 yuan/kWh. The total costs of a wind power project consist of construction costs, maintenance costs, loan interests, salary costs, and taxes. The most important “raw material”, wind resource, is free. Although the construction costs of wind farms in Inner Mongolia experienced a steady decline over the past two decades (Li et al., 2005), the relatively high production costs of wind electricity – compared to fossil-fueled electricity – is primarily caused by high construction cost of wind farms (Lew and Logan, 2001; Mathew, 2006). Currently, the average construction cost – consisting of equipment, infrastructure, the building process, and land rents – is estimated to be around 10,000 yuan/kW installed capacity. The majority of the wind turbines installed in Inner Mongolia are imported from overseas. Key components of domestically made turbines are also imported. In comparison, imported turbines and components are 30% more expensive than domestic ones. As a result, depreciation of equipments accounts for a large proportion of generation cost of wind electricity, compared to coal electricity. To maintain equipment, a wind farm needs to pay about 0.15 yuan for every kWh of electricity it generates. The average rate of interest on loans for wind farms is about 9% of the total costs. Salary of employees is estimated to be about 0.07 yuan/kWh. Another 0.03 yuan/kWh relates to other issues in wind farm management. Taxes imposed on wind farms include value-added tax (VAT)⁷ and income tax.⁸ Import tariff and VAT on imported goods are refunded.⁹ Approximately, on average wind farms pay 0.17 yuan taxes for every kWh of electricity.

High generation costs make wind electricity less competitive in comparison with fossil-fueled electricity. When there are still

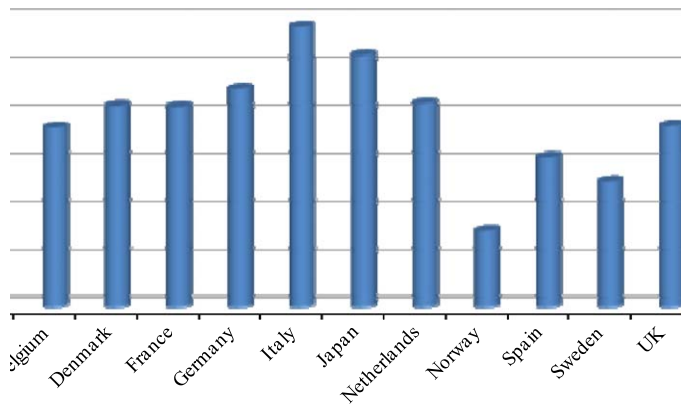


Fig. 6. Comparison of wind power price in China (2007) with foreign countries (2004) (Sources: Li et al., 2005; author's calculation).

abundant fossil fuel resources available in the world, no power company is willing to afford less benefits – or even economic losses – through the development of a large capacity of wind power. Currently, the incentive for power companies to develop wind power is mainly in anticipation of renewable portfolio policy and increasing fossil fuel prices in the future. If no further stimulation policy measures are taken and fuel prices remain fluctuating, power companies will quickly lose enthusiasm in wind power development.

Secondly, low profits are caused by cheap wind energy prices. Wind farms gain limited income by selling electricity to the power grids. In 2007, average wind electricity price in China was only 0.63 yuan/kWh. It is lower than wind electricity prices in 2004 in most western countries with a well-developed wind power sector (Fig. 6). The only countries with wind electricity prices lower than China were Norway (0.32 yuan/kWh), Sweden (0.53 yuan/kWh) and the United States (0.55 yuan/kWh). However, in Norway up to 25% of the construction cost for wind farms is subsidized by the national government. Wind farms in Sweden receive an “ecological award” equaling 0.225 yuan/kWh, while wind farms in the United States get 0.126 yuan/kWh tax refund. Furthermore, wind resources in all three countries are better than in China, which lowers their costs of wind electricity generation.

Low price of wind electricity in China has its institutional reasons. As mentioned above, the price of wind electricity is formed in two different ways. If the wind power project is directly – that is, not in competition – contracted by NDRC/IMDRC to the company, the electricity price is decided by NDRC/IMDRC when the project is approved. The price is then normally high enough to ensure wind farms an economic profit. Under the concession contract, the price is set differently. In order to win the concession bid, and partly due to an overestimation of the on-grid price in the future, wind power enterprises are inclined to take high risks and set a low price in their bids for the first 30000 full load hours. As a result, the average wind electricity price of concession projects is much lower than the electricity price of government contract projects (see Table 3). The low purchasing price offered by winning concessions provides little incentives for further investments.

High generation costs and low on-grid prices of wind electricity have a direct impact on current wind power development in China: many power companies wait with further investments until the wind power market proves mature and profitable. The Chinese wind power industry seems to be caught in a vicious circle of “high costs/low price – insufficient investment – high costs”.

The second phase of Huitengxile Wind Farm can be taken as an example for roughly assessing the economic profits of a wind farm

⁷ Wind farms enjoy a preferential VAT rate of 8.5%, half of the rate normal enterprises are experiencing.

⁸ Refunded completely in the first 2 years, refunded for 50% in the next 3 years (which means a tax rate of 16.5%), and experiencing the full rate (33%) afterward.

⁹ Source: Ministry of Finance File No. 36[2008], “Policy on adjusting import tax of wind turbine components”.

Table 3

On-grid price of wind electricity of major wind farms in China.

Wind farm	Location	Price (yuan/kWh)	Pricing mechanism
Huitengxile	Inner Mongolia	0.382	Concession project
Bayin	Inner Mongolia	0.466	Concession project
Huitengliang	Inner Mongolia	0.420	Concession project
Rudong	Jiangsu	0.436	Concession project
Baoligenshan	Inner Mongolia	0.648	Government contract
Zhurihe	Inner Mongolia	0.609	Government contract
Dashanwan	Shangdu	0.609	Government contract
Dabancheng	Xinjiang	0.533	Government contract

Table 4

Cost and benefit information of Huitengxile Wind Farm (39.6 MW).

Cost		Benefit	
Construction costs (yuan/kW)	10901	Electricity price (yuan/kWh)	0.382
Interests (yuan/kWh)	0.041	Electricity generation (10 ⁶ kWh/yr)	142.97
Salary costs (yuan/kWh)	0.068		
Maintenance costs (yuan/kWh)	0.156		
Other costs (yuan/kWh)	0.034		

in Inner Mongolia. This project started in October 2005 and the turbines came into use at the end of 2006. Total investment for the second phase reached 516.5 million yuan, with 39.6 MW installed capacity and a designed operational lifetime of 20 years. The electricity price in the concession contract was 0.382 yuan/kWh (post-tax). Information on economic costs and benefits is listed in Table 4. During its operating lifetime, the wind farm generates 2854.9 ($142.97 \times 20 = 2854.9$) million kWh of electricity. The construction cost per kWh electricity is 0.181 yuan and the total cost per kWh electricity is 0.450 yuan. However, during the first 30,000 full load hours (8.3 years) the electricity generated by this wind farm is sold to the grid at a price of 0.382 yuan/kWh, resulting in an annual deficit about 10 million yuan. This deficit can be compensated only if the generation cost of wind electricity is reduced significantly to 0.334 yuan/kWh or if the price of electricity after that is increased to 0.5 yuan/kWh.

6. Technological performance of wind power projects

The third performance indicator of wind power development is technological performance. We will especially pay attention to three sub-indicators: site selection, average scale of individual wind turbines, and the localization of wind power manufacturing.

6.1. Site selection

A suitable site for a wind farm influences its technological as well as economic performance. Richness of wind resources, transportation conditions and distance to the power grid are main criteria for selecting wind farm sites.

The amount of potential wind energy depends mainly on wind speed at site and to a lesser extent on the density of air, which is determined by air temperature, barometric pressure, and altitude. For any wind turbine, the power and energy output increases when the wind speed or air density increases (Abderrazzaq, 2004). Therefore, it is crucial for a wind farm to be located in areas with high and stable wind speed. Besides a favorable meteor-

ological situation, convenient transportation and access to power grid are vital for lowering construction and operational costs of a wind farm. Close distance to railways or highways helps reducing transportation costs during the construction of wind farms. Convenient conditions to transmit electricity to the grid are necessary for large scale electricity generation by wind farms.

These three indicators – wind resources, transportation and access to power grid – were applied to assess technological performance of the three wind farms selected for case study (Table 5).

All three wind farms are located in rich wind resource areas, according to the National Standard for areas with rich wind resources. In comparison, Huitengxile wind farm is richer in wind resources than the other two. Although average wind speed in Huitengxile is the lowest among the three farms, the longer time of effective wind speed compensates this disadvantage. Transportation conditions are somewhat different among the three. Huitengxile Wind Farm does not have convenient access to railway, but it locates at a province-level expressway. Zhurihe and Dashanwan are very close to the railway system. Both wind farms constructed roads to railway stations nearby.

Connection to power grid has become a bottleneck for wind power development in Inner Mongolia. Within the three wind farms, Huitengxile is the only one who has a convenient connection to power grid. The electricity it generates is sent to a 110 kV grid across the wind farm. However, the grid can not satisfy further development of the wind farm. Zhurihe needed to build an additional transmission line to the grid 9 km away. The 35 kV power grid across Dashanwan was too small. An upgrade proved essential to improve electricity transportation efficiency.

Grid expansion is too costly for power companies. In China the average cost to construct 100 km of transmission line is 350 million yuan. Upgrading the power grid is even more expensive. Wind farms are normally built in remote areas. Power companies can hardly afford the construction cost of transmission line from the main power grid to their wind farms. Although it is stated in concession project policies that “the power grid company will construct transmission line to the wind farm”, there is no obligation regarding the time the construction should be finished or the standard of transmission line. Behind the booming wind farm construction, it is also notable that slow down in power grid construction can delay future development of wind power in China.

6.2. Average scale of individual wind turbine

At a given location, efficiency of wind power generation increases when average turbine scale increases. It is a worldwide trend that the scale of individual turbines is becoming larger and larger. Nowadays, 1500 and 2000 kW turbines are prevailing in the international wind turbine market (Shi, 2008b).

The average scale of wind turbines installed in each year in Inner Mongolia shows a steady increase from 1989 to 2007, with an exception in 2000 (Fig. 7). The minimum scale of individual turbines is 100 kW, which was installed in Zhurihe in 1989. The maximum reached 2000 kW, which were turbines installed in Caoduozi, Bolike, and Bayinxile in 2007. It is the largest scale of individual (onshore) turbines in China and comes close to the prevailing scale in the western world.

6.3. Localization of wind power system manufacture

According to the Global Wind Energy Council (2008), China is now the fastest growing wind power market in the world, while Inner Mongolia is the fastest growing wind power market in

Table 5
Site situation of three wind farms in Inner Mongolia.

Wind farm	Wind speed (m/s) ^a	Effective wind speed (h) ^b	Wind power density (W/m ²)	Transportation condition	Distance to grid
Huitengxile	7.2	6255	662	38 km from railway; highway across	50 km from 220 kV; 110 kV across
Zhurihe	8.1	5808	554	9 km from railway	9 km from 110 kV
Dashanwan	7.8	5628	447	0.5 km from railway	35 kV across
Standard ^c	>6	>5000	>300	–	–

^a At 10 m height.

^b 5–25 m/s at 10 m height.

^c National standard for area of rich wind resource.

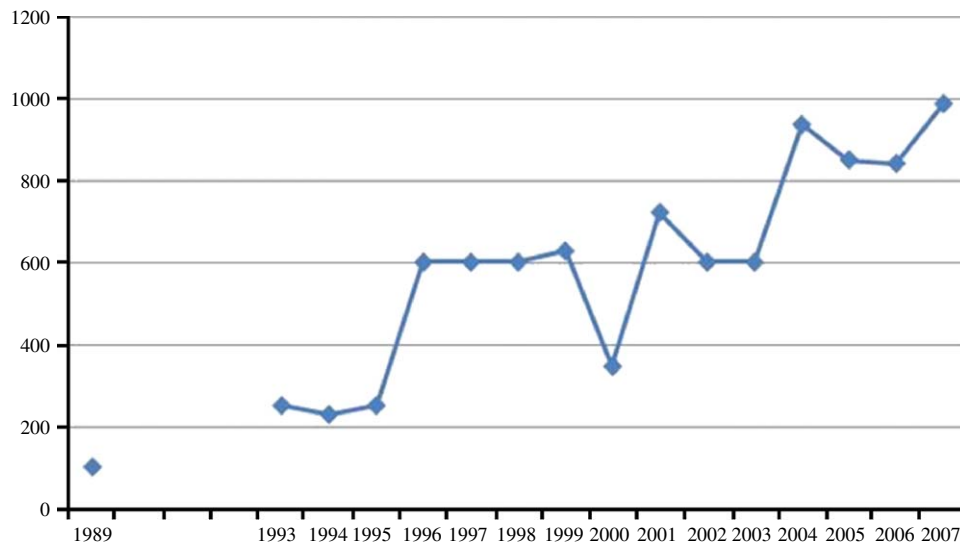


Fig. 7. Average scale of turbine installed in Inner Mongolia.

China. Increase in the use of domestically produced wind power systems can significantly reduce the construction costs of wind farms. Due to the reduction in purchasing price, transportation costs and custom tariffs, domestic wind turbines are about 30% cheaper than imported turbines.¹⁰ Domestic turbines also have advantages in better adaptation to Chinese or Inner Mongolian circumstances, short delivery terms and convenient/cheaper after-service.

There are three types of wind turbine manufacturers in China: domestic-owned, joint ventures and foreign-owned. The market share of the former two types of enterprises is considered an indicator of the maturity of China's domestic wind turbine industry. Of all wind turbines produced in China up till now, there are more turbines manufactured by foreign-owned enterprises (53%) than those by domestic-owned (45%) and joint-venture enterprises (2%). This is partly caused by the short history of domestic wind turbine industry in China. A factor in the stagnating development of the domestic wind turbine industry was the high import tax of wind turbine components before 1997.¹¹ Domestic enterprises without wind turbine R&D capacity could not afford the cost of importing wind turbine components.

This situation did not change until it became mandatory that every turbine in concession projects meet the 70% domestic cost

content requirement. Since then, the proportion of domestic turbines was included as one of the assessment indicators in evaluating bids of concession projects. The developer was also required to include a domestic manufacturer into the bidding team. All these policy measures provided opportunities for China's wind turbine companies to boom. Therefore, in 2007 in China the proportion of wind turbines manufactured by domestic-owned (56%) and joint-venture enterprises (2%) exceeded those by foreign enterprises (42%). The proportion of domestic wind turbines installed in Inner Mongolia also experienced rapid increase in the past decade. Before 2000, no domestically produced wind turbines were installed in Inner Mongolia, while in wind farms established in Inner Mongolia in 2006 and 2007 domestically manufactured wind turbines dominated with 55.7% and 58.9%, respectively.

Along with the market-oriented reform of wind power industry in China, a local wind turbine industry is evidently being developed in China. There are now over 20 domestic wind turbine manufacturers such as Goldwind, Huarui, Wandian, Huiteng, Longyuan, Zhonghang, and Yunda. Most of them have the technological capability to manufacture wind turbines with a generating capacity of 750 kW, and some are in the process of developing megawatt-scale turbines. Several demonstration projects have domestic 1.2 and 1.5 MW wind turbines (Shi, 2008b).

However, there are obviously shortcomings of increasing localization of wind turbine manufacture in China. First, most local wind turbine companies still need to purchase core

¹⁰ However, already 70% localization rate is required. The potential for additional cost reduction is somewhat limited in this respect.

¹¹ It is now totally refunded, according to State Council File No. 37[1997], "Circular on adjusting tax policy of imported facilities".

components, such as the rotor and gearbox, from overseas. They manufacture only supporting systems that account for a small proportion of the total costs of the entire wind turbine. Consequently, the construction costs of wind farms cannot be reduced significantly before these core components are manufactured domestically.

Second, cooperation with foreign companies results in the transfer of wind power equipment rather than technologies. This transfer of hardware (equipment) is helpful in meeting localization criteria in short term, while the transfer of software (knowledge and technology) is more important for the establishment of a successful domestic wind turbine industry in the long term.

Third, domestic wind turbine technology is still immature. Wind farms need to pay more time and money to maintain domestic turbines than imported ones. The immature domestic technology also results in wind turbines frequently breaking off. It is estimated that average full load hours of wind turbines in Inner Mongolia was 1933 h in 2007 (Shi, 2008a). It is higher than the national average (1787 h), while much lower than that in western countries such as United Kingdom (2628 h), Australia (2500 h) and United States (2300 h). In some (extreme) cases, a wind turbine with 2000 designed full load hours can actually be in operation for only 300 h a year.¹² Besides technical reasons, some researchers also ascribe the problem of low full load hours to the prevailing policy system that is more focused on installed capacity than actual utilization of wind resource. There are no statistics on real electricity produced by wind farms. MW, instead of MWh is the only criterion for assessing wind power development in China (Shi, 2008a).

7. Environmental and social impacts

7.1. Environmental impacts

Environmental impacts of wind power development in Inner Mongolia refer to the impacts of wind power development on local environmental quality.

The Chinese government has set the objective of 10% air pollutant reduction between 2006 and 2010 in its 11th National Five-Year Plan, and wind power will be an important contributor to reduce air emission pollution from energy generation. For every 1000 kWh of wind electricity generated, 600 kg CO₂, 2.1 kg of soot, 4.76 kg of SO₂ and 31.5 kg of solid waste emissions are reduced. In addition, 2520 kg of water and 290 kg of coal is saved (Huang, 1993; Li et al., 2005). Totally 1.334 billion kWh of wind electricity generation in Inner Mongolia in 2007, which resulted in a substantial prevention of emissions, as listed in Table 6.

Wind power also has negative impacts on the local environment. Previous investigations showed that developing wind power could cause noise pollution, visual pollution, and threats to birds. It is notable that in Inner Mongolia these environmental problems are not as serious as initially thought. First, most local residents live at least 1000 m away from wind turbines. The average noise levels of wind turbines in operation in Inner Mongolia is only 31 dB (A) at a distance of 1000 m, equal to noise level in bedroom. Second, wind turbines in Inner Mongolia are constructed on wide-open grasslands, with little human activity. Therefore, wind power projects in this region hardly cause visual pollution. Third, all wind farms in Inner Mongolia had to pass an environmental impact assessment (EIA) before construction. An

Table 6

Pollutants reduction by wind power generation in Inner Mongolia.

	Soot (1000 t)	SO ₂ (1000 t)	Solid waste (1000 t)
Reduction	2.8	6.4	42.0
Total emission	778.0	1456.0	73630.0
Proportion (%)	0.36	0.44	0.06

important part of an EIA concerns the impact of the planned wind farm on birds. Wind farms planned on migratory routes of birds are not allowed and need to be re-planned. Although data on actual bird mortality through wind farms are not available for Inner Mongolia, statistical analyses showed that there is only a very small chance for birds to be hit by wind turbines (Li et al., 2007).

7.2. Societal influence

Societal influence of wind power development in Inner Mongolia considers whether wind power projects satisfy societal needs.

Nationally, the growth of domestic wind turbine industry offers employment in R&D, manufacturing and selling of wind power products. At the local level, the construction and maintenance of wind farms create new job opportunities for local people in wind farms. Although wind farms are not labor-intensive, labor is needed for constructing wind farm, regularly monitoring wind turbines, guarding equipments, and maintaining turbines and other facilities.

Developing wind power increases total domestic energy production and thus energy security of the region. Inner Mongolia generated 1.334 billion kWh of wind electricity, 1.5% of its total electricity consumption in 2007. Although this proportion cannot be compared with that in Western countries, the steep increase promises contribution to Inner Mongolia's and China's future energy security.

There are also social benefits indirectly related to wind farms. Due to the establishment of wind farms, local transport and traffic conditions are often improved. Most wind farms in Inner Mongolia locate at remote and mountainous areas, where poor traffic conditions used to be a major limiting factor for economic development. After wind farm construction, improved road infrastructure facilitated transportation and mobility of persons and goods, and thus economic development. During our surveys in Inner Mongolia we found that more than two third of the hotels and restaurants around wind farms were established after the construction of the wind farm. All interviewed hotel and restaurant owners agreed that their business increasing due to the wind farms. Construction of wind farms also brings localities additional tourism resources. For example, the Huitengxile Wind Farm became an important attraction of Qahar Youyi Zhongqi, the city where this wind farm locates. Now about half of the local residents' daily income is gained from tourists.

However, developing wind power in Inner Mongolia also encounters societal problems. Wind power development in Inner Mongolia lacks communication between developers and local residents. The most important problem is that local governments do not have enough influence on the establishment of wind farms in their territory, nor do they have influence on the way wind farms are run. There is a potential conflict between local economic benefits and wind farm development in the future, since a large area of land will be used for a long time without sufficient compensation to local people. Besides, herdsman's production is

¹² As was the case for three Huarui wind turbines installed in Boligenshan Wind Farm in 2003.

influenced by wind power projects. During the construction of wind farms (normally 1–2 years), grassland (about 1 ha for each turbine) is not available for grazing. After construction is completed, the grassland needs to recover at least 1 year and that needs substantial human intervention such as leveling land, seeding and irrigation. Another problem relates to the security of wind farm facilities. Normally wind farms are very large and located on land open to the public. Wind farm managers complain that local residents steal components of wind turbines, especially at an early stage of wind farm completion. How to protect wind turbine components from being stolen bothers wind farm managers already for a long time.

8. Conclusion and recommendations

Wind power in China is recently experiencing a rapid growth. Our research in Inner Mongolia illustrates the major environmental, energy security and social benefits that wind power development brought to this region. At the same time, this research also reveals several complications in wind power development: high generation cost, low on-grid price, as well as immature domestic manufacturing. These shortcomings need to be removed as they might complicate further wind power development in China towards levels that are now experienced in countries such as Denmark and Germany. To this end, three policy recommendations are put forward, to secure further development of wind power in Inner Mongolia and China.

8.1. Fossil fuel tax

In comparison with fossil-fueled (especially coal-fueled) electricity, wind electricity is still too expensive. Many experts have argued that the cost of fossil-fueled electricity is calculated improperly (Costanza, 1980; Durning, 1992; van Kooten et al., 1999). Electricity generated from fossil fuels has major negative impacts to the local environment and human health, while conventional calculation methods do not include these costs (externalities) into fossil-fueled electricity costs and prices. To produce a level playing field for the various electricity producers, the actual costs of fossil-fueled electricity need to include environmental externalities, i.e. the cost of environmental pollution, human health and resource exhaustion. In the research project “ExternE” (European Commission, 1995), it was estimated that if the externalities of fossil fuel are included, costs of coal electricity is anticipated to double. Based on this presumption, cost of coal electricity in China will then increase to 0.6 yuan/kWh, making wind electricity fully competitive with coal electricity.

An important policy measure that can realize the internalization of environmental externalities is fossil fuel tax. If the tax rate is properly designed, cost of fossil-fueled electricity will be increased to an equal level as that of wind electricity. Besides, part of the money raised from fossil fuel tax can be allocated to renewable energy (including wind energy) technology R&D. China has not yet started to use such taxes on fossil-fueled power generation. However, this topic has been discussed for years and is expected to be implemented sooner rather than later (Hai, 1999; Wang, 2007).¹³

¹³ On December 19, 2008, when this article was under review, China's national government announced an increment of the fuel-oil consumption tax from 0.1 to 0.8 yuan a liter starting at the beginning of 2009. We expect that the same policy will be applied in the power generation sector in the near future.

8.2. Reformed concession model

The concession model is a typically Chinese policy arrangement for stimulating wind power development. As analyzed in this paper the main problem of the concession model is the extremely low grid price offered by winning concessions, and the subsequent lack of further investment. Although through the concession model the Chinese government intended to select the most suitable wind farm developer, in practice the main (and sometimes only) selection criterion became the lowest on-grid price offered. Of all the winners of concession projects in China, only Longyuan Power Group & Hero Asia Company Limited succeeded in winning the Bayinxile Wind Farm project without bidding the lowest price (Meyer, 2006). The concession model for wind power development in China needs to be reformed on two points: fixed on-grid price and improved localization policy.

Firstly, a fixed feed-in tariff should be set for concession projects. Although China has set up feed-in policy for wind electricity generated under concession projects, the on-grid price of wind electricity is not fixed. Our survey among wind power companies revealed that these companies do not applaud the “two-step” pricing mechanism of China's concession model (i.e. different prices before and after the first 30000 h full capacity generation), because it causes vicious competition in bidding for concession projects. Although NDRC modified the bidding rules by adding evaluation criteria of wind developing condition (site selection, technology selection, efficiency of project development, etc.) and the “mid-price” evaluation routine for the latest phases of concession projects to avoid vicious competition, this situation did not really change and the price setting procedure is obviously unreasonable.

If there is a fixed feed-in tariff for concession projects, wind power developers just need to concentrate on the creation of the best wind developing condition. Such feed-in tariff can be different among regions and project types, following an integrated consideration of wind resources, project characteristics, on-grid price of fossil-fueled electricity and purchasing power at site (Jobert et al., 2007). At the end of 2007, Guangdong province started to set feed-in price of wind electricity at 0.689 yuan/kWh, which is 0.25 yuan/kWh higher than the on-grid price of fossil-fueled electricity.¹⁴ It is a helpful attempt towards setting fixed feed-in wind power prices, and at the same time bridging the economic gap between wind power and fossil-fueled electricity production.

Secondly, the localization policy of wind turbine should be improved. China is strongly promoting local manufacturing capacity and capability of wind turbines. The mandatory localization rate policy has shown its function in expanding domestic supply markets and reducing costs. However, two aspects of the localization policy can be improved. First, not only the quantity but also the quality of localized turbines should become an important policy objective. Quality criteria can relate to individual turbine scales, annual full load hours, lifetime of turbines, etc. Second, one turbine manufacturer should be allowed to sign contracts with more than one developer in bidding for the same concession projects.¹⁵ In this way, turbine manufacturers with better resources will have more opportunities to develop and mature in a short term.

¹⁴ Coincidentally, the NDRC document “Measures for Pricing and Cost Distribution of Renewable Energy Electricity” states that the on-grid price of electricity generated from bioenergy should be 0.25 yuan/kWh higher than that of fossil-fueled electricity.

¹⁵ In the concession projects policy, business contracts between wind farm developer and turbine manufacturer are exclusive.

8.3. Enhanced international cooperation

China has a relatively short history of wind power development, with a comparable shortage of experience and infrastructure. International cooperation is of vital importance for the further development of wind resource utilization in China. Although China has made significant efforts in international communication and cooperation, this can be further enhanced.

In order to improve international communication of wind energy science and technology, it is meaningful to establish joint research institutes, which can be a combination of Chinese research institutes and their foreign counterparts, or new institutes consisting of Chinese and foreign experts. Joint research institutes can function in developing wind turbines that apply advanced technology from western countries while fitting China's unique environmental and social circumstance. These institutes are also helpful in properly understanding learning experiences from wind power promotion policies in western countries.

Another important content of improved international cooperation is capacity building. Due to the localization rate criterion of the concession model, domestic turbine manufacturers are more inclined to import hardware (components) than software (manufacturing knowledge/technology). However, the latter is much more important for the long-term development of the domestic industry. If the domestic wind industry is to mature, the government should further support both cross-boundary transfer and domestic innovation of wind power technology other than import of equipments.

It is also worth trying to involve overseas power companies into the bidding for concession projects. Currently developers of concession projects are all domestic power companies, sometimes linking with joint-venture turbine producers. However, both the financial resource and technology level of domestic companies are limited. In the process of improving international cooperation to spur technological development, it is worthwhile to try involving overseas power companies into the bidding for concession projects. Besides providing more financial resources and advanced wind power technology, overseas power companies are also expected to provide long-term maintenance and service.

Acknowledgments

The authors are grateful for the support provided by the National Basic Research Program of China (973 Research Program) with Grant no. 2007CB407307, the Knowledge Innovation

Program of the Chinese Academy of Sciences with Grant nos. KZCX2-YW-420-5, KZCX1-YW-06-05-02, and International project between the Netherlands Royal Academy of Arts and Sciences and the Chinese Academy of Sciences with Grant no. 08CDP005.

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