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Wind power generation in China: Understanding the mismatch between capacity and generation

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A B S T R A C T

The Chinese government has made an important effort to diversify the country's energy mix and exploit different sources of renewable energy. Although China's installed wind power capacity has experienced a dramatic expansion over the past five years, electricity generation from wind power has not increased as expected. This paper aims to present the current status of wind generation in China and analyze the causes of the large discrepancy between installed capacity and generation. We find that this is mainly caused by the inadequacy of the power transmission grid, the absence of economic incentives to transmission and backup generation providers, and the lack of a generation-based renewable portfolio standard.

1. Introduction

China's energy system relies heavily on fossil fuels and due to its tremendous demand growth since 2007 it has become the biggest emitter of CO_2 in the world. The total energy consumption in China reached 3.25 billion tons of standard coal equivalent in 2010 [1], surpassing the US as the world's largest energy consumer. If carbon intensity kept pace with a GDP growth rate of 7%, by 2030, China would be emitting as much CO_2 as the world emits today [2]. With the goal of diversifying its current energy mix dominated by fossil fuels and reducing GHG emissions, the central government has set the ambitious target of making non-fossil energy sources account for 15% of the primary energy consumption by 2020 [3]. This requires 35% $\sim$ 40% of China's electricity to be generated from renewable sources by then.

Recognizing that wind is one of the most abundant, clean, and economical sources of renewable energy [4,5], in 2008, the newly-established National Energy Administration made the development of wind energy a priority for diversifying China's energy mix [6]. Although considerable efforts have been made to increase installed wind power capacity, the output of wind farms accounted for merely 0.75% of China's total electricity generation in 2009 [7].

Recently, a number of studies have tried to uncover the main barriers restricting the full utilization of China's existing wind farms in electricity generation. Wang [8] concludes that wind-generated electricity fails to keep pace with the increasing wind power capacity mainly due to the inadequate transmission grid and the lack of a renewable portfolio standard (RPS), that explicitly requires power companies to generate power from renewable energy, and not just to increase capacity. Wang et al. [9] draw similar conclusions, stating that a market-based mandatory RPS coupled with strong regulatory monitoring of transmission companies should be introduced. Zhao et al. [10] point out that insufficient power grid capacity is the main obstacle encountered by the wind power industry in the Jiangsu Province, which has rich wind energy resources. Yu and Qu [11] argue that current policy in China should be re-designed to ensure economic incentives for wind power generation given that currently most of the existing wind farms do not make any profit.

Other barriers to wind energy include poor market acceptance, imperfect capital markets, and technology prejudice [8]. Just as Sovacool [12] states, utility and operator objections to intermittent renewable energy may be less about physical limitations and more about tradition, familiarity, and arranging social and political order.

In this paper, we present recent data on installed wind power capacity and generation to show how the utilization of wind power capacity has been declining in recent years; and we review existing policies affecting the industry to shed some light on the main factors explaining this situation. The rest of this paper is organized as follows: Section 2 briefly reviews the policies and market conditions that have helped increase installed wind capacity;

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Section 3 presents data on recent wind power generation; Section 4 discusses some possible explanations for the large discrepancy that exists between installed wind power capacity and generation; and Section 5 presents our conclusions.

2. Wind power installed capacity growth and the three factors that have made it possible

Wind power capacity in China has experienced a dramatic expansion in recent years (Fig. 1). By the end of 2010, its cumulative installed capacity has reached 44.7 GW [13], making China the country with most installed wind power capacity in the world. Furthermore, this figure is estimated to increase to 200 GW by 2020 and 404 GW by 2030, respectively, according to the projection of the Global Wind Energy Council under the business as usual scenario [14]. A number of factors explain this growth in installed wind power capacity: 1) the realization that China is endowed with large wind resources; 2) the enactment of policies that create economic incentives for the installation of wind capacity; and 3) the reduction in wind power capital costs.

2.1. Encouraging revised estimates of wind resources

China is endowed with large wind resources in the northern regions, from Xinjiang through Gansu Province to Inter Mongolia, and in the southeast along the coastline [15]. According to the latest version of wind resources assessment published by the China Meteorological Administration at the end of 2009, China has the potential to develop 2380 GW of on-shore wind power for class 3 (measured at a relatively height of 50 m above ground) and 200 GW of offshore wind resource (water depth 5–25 m) [16]. This estimation for on-shore wind energy resources is nearly 10 times of what had been reported in earlier versions.

2.2. Policy incentives for wind power

China has implemented a series of policy mechanisms for the development of their wind power industry with some positive results (Fig. 3). In what follows, we provide a brief summary of these policies in chronological order.

2.2.1. Wind power concession projects (adopted in 2003)

The National Development and Reform Commission (NDRC) adopted the mechanism of concession projects in 2003 in order to promote the commercialization of China's wind power industry. Under this approach, the NDRC offers several selected locations for concession projects and chooses the investors through competitive bidding. The government ensures that all electricity generated by the bidder's wind farms will be purchased by a local provincial

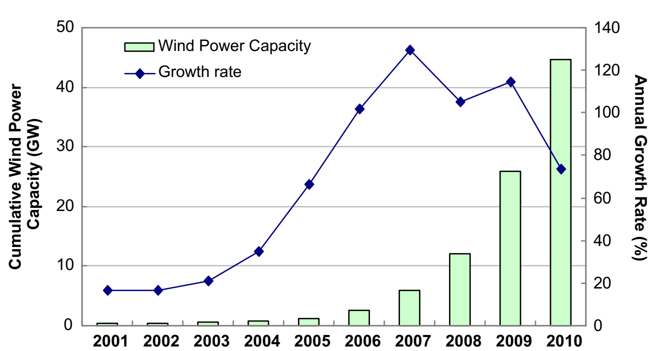

Fig. 1. Cumulative wind power capacity and annual growth rate during 2001–2010.

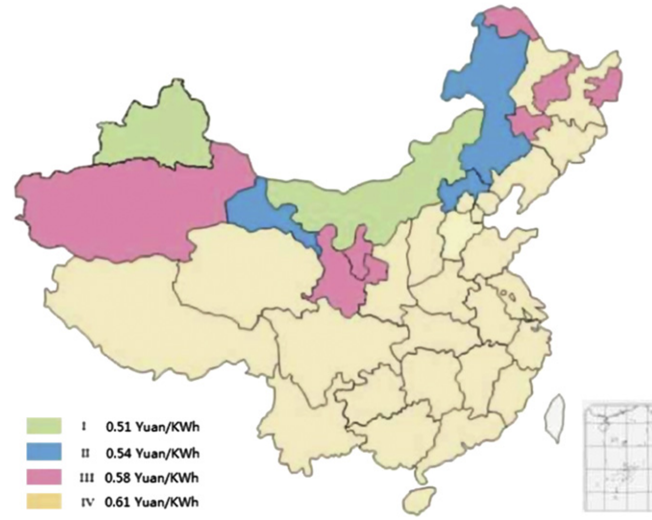

Fig. 2. NDRC Regional divisions for wind power prices [21].

transmission company. Moreover, the transmission company is mandated to provide the power transmission lines required for connecting the concession wind farms to the nearest network [4,8,17].

2.2.2. Renewable energy law (promulgated in 2005)

Despite the benefits of the concession wind projects, the dramatic increase of installed wind power capacity only took off in 2005 after the Renewable Energy Law (REL) was promulgated. This law makes the development and utilization of renewable energy a priority by mandating that transmission companies purchase all the electricity generated by registered renewable energy enterprises. Moreover, a range of financial incentives were also proposed to promote the development of renewable energy [18].

2.2.3. Provisional administrative measure on pricing and cost sharing for renewable energy power generation (implemented in 2006)

There is no doubt that transmission companies were unwilling to purchase the renewable electricity generation due to its much higher on-grid price compared with conventional power sources. For a balance of interests between the producers and purchasers, a Provisional Administrative Measure on Pricing and Cost Sharing for Renewable Energy Power Generation was issued merely three days after the REL came into force. This regulation states that transmission companies may recover from their customers (1) expenses for getting renewable electricity connected to the grid, and (2) the difference between expenses for purchasing renewable electricity and those for purchasing fossil fuel electricity of the

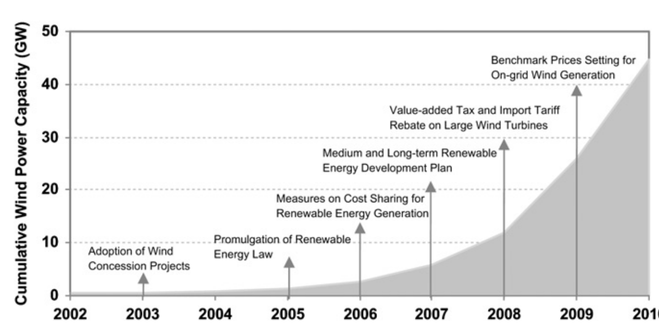

Fig. 3. Impacts of different policies on wind installed capacity.

same amount [9]. Due to this measure, transmission companies can buy wind power without incurring any extra cost.

2.2.4. Medium and long-term renewable energy development plan (enacted in 2007)

In order to further promote the development of renewable energy, the *Medium and Long-term Renewable Energy Development Plan* was enacted in 2007. It mandates that 15% of China's final energy consumption should come from renewable resources by 2020. In addition, an (installed-capacity-based) renewable portfolio standard was introduced, stating that for power producers with an installed capacity of more than 5 GW the share of installed capacity from renewable energy resources (not including hydroelectric power) should reach 3% by 2010 and 8% by 2020, respectively.

2.2.5. Value-added tax and import tariff rebate on large wind turbines and key components (implemented in 2008)

With the goal of creating incentives for the domestic production of large wind-turbines, the Ministry of Finance (MOF) brought forward two regulations: (1) an import tariff and value-added tax rebate program for importing key components and raw materials used in large wind-turbine manufacturing, effective in January, 2008; and (2) the cancellation of a tariff-free policy for importing wind turbines with capacities lower than 2.5 MW in May 2008 [19,20].

2.2.6. Notice regarding the price policy of grid-connected wind power (implemented in 2009)

The NDRC divides mainland China into four regions based on the nature of wind energy resources and the infrastructure conditions. For each of these regions, benchmark prices ranging from 0.51 Yuan/KWh to 0.61 Yuan/KWh have been established, as shown in Fig. 2. All newly-built on-shore wind power projects since August 1, 2009 receive the local benchmark prices.

Fig. 3 illustrates the impact that the different policies discussed above have had on wind power installed capacity.

2.3. Decreasing capital costs for wind energy (and increasing cost for competing coal)

Currently, the main incentives to develop wind power are the decreasing capital costs of wind-power generation in conjunction with an increase in fossil fuel prices. On the one hand, wind power generation costs have declined observably with the technological progress in turbines manufacturing, which accounts for 70% of the total capital investment cost. For example, in the competitive bidding for providing wind turbines to the 10 GW-scale wind power bases of Hebei and Xinjiang, the quoted price of one of the successful bidders (Goldwind Science & Technology Company) for the 1.5 MW scale wind turbines was only 3850 Yuan/MW. This represents a substantial reduction compared to the price of 6200 Yuan/MW in the beginning of 2008 [22]. On the other hand, the sharp rise in coal prices since 2004 [23] has put the coal-fired generation industry in a difficult situation. All the coal-fired power plants in ten provinces[1] in China had financial losses during the first three quarters of 2010 [24].

3. The problem: low levels of wind power generation

Despite growth of installed wind power capacity, wind generation remains low. The capacity factor of wind farms in China is extremely low; and the discrepancy between installed capacity and generation has increased in recent years.

3.1. Annual capacity factor

The capacity factor is defined as the ratio of actual annual energy output of a wind farm to its output if all turbines were running at full rated capacity for the entire year [25]. It expresses how effectively the wind turbine harnesses the energy available in the wind spectra [26], and is a central concern for both manufacturers and public decision makers [27]. An expression for the annual capacity factor of a plant in a year t (CF(t)) is given by:

$$\mathrm{CF}(t) = \frac{\mathrm{WG}(t)}{C(t) \times 8760} \tag{1}$$

Where WG(t) is the total wind power generation delivered to the grid in year t (in MWh), $C(t)$ is the total installed capacity of wind power in the corresponding year (in MW), and 8760 represents the number of hours in a year. Considering the fact that cumulative wind power capacity in China has increased dramatically in recent years, $C(t)$ is represented by the mid-year installed capacity as shown in Eq. (2), where $C'(t)$ represents installed capacity at the end of year (t)

$$C(t) = \frac{C'(t-1) + C'(t)}{2} \tag{2}$$

Based on data of annual wind power capacity and generation during the years 2007–2010, we estimate the annual capacity factor in the country. Data on annual wind power generation WG(t) comes from the Chinese Electricity Council [7,28] and <China Electric Power Yearbook 2008> [29]; while the information on cumulative wind power capacity $C(t)$ is from a report from the Chinese Wind Energy Association [13]. Table 1 shows that all the annual wind capacity factors during the years 2007–2010 were below 17%.

3.2. Decreasing utilization of wind power generation

In order to understand the extremely low capacity factor of wind power in China and to put it into context, it is necessary to distinguish between *availability* and *utilization* of wind power generation. The annual *availability* of wind power can be expressed as the potential wind generation (PWG) in the year given by:

$$\mathrm{PWG}(t) = C(t) \times T \tag{3}$$

Where T is the number of hours wind power was *available* to run turbines at full capacity, and $C(t)$ is as defined in Eq. (2).

If the capacity factor is equal to the availability factor, all available power has been utilized. However, if availability is higher than the capacity factor, some obstacles must be preventing the full utilization of the available wind power (i.e. there is curtailment). To

Table 1
Comparison on the real and potential wind generation in China.

Year	WG (TWh)	PWG (TWh)	Capacity factor	Availability factor	Utilization factor
2007	5.71	NA	0.155	NA	NA
2008	13.08	18.30	0.167	0.234	0.715
2009	27.62	39.28	0.167	0.237	0.703
2010	50.10	73.96	0.162	0.239	0.677

Caption: Availability factor here is defined by the ratio of the hours wind power was available to run turbines at full capacity in a year to the total number of hours (i.e., Availability factor = T/8760); Utilization factor is defined as the ratio of capacity factor to availability factor (i.e. Utilization factor = capacity factor/availability factor).

[1] The ten provinces include Shanxi, Henan, Anhui, Hubei, Hunan, Jiangxi, Shandong, Heilongjiang, Jilin and Liaoning.

estimate the average utilization factor of wind power in the country we obtained data on T from a report compiled by the State Electricity Regulatory Commission (SERC) [30]. Table 1 shows a comparison between China's annual availability - PWG(t) - as defined in Eq. (3) and total annual wind power generation delivered to the grid - WG(t) - as defined for Eq. (1), along with the average capacity, availability, and utilization factors for the years 2008, 2009 and 2010:

As shown in Table 1 the utilization rate of wind power has been decreasing in the last 3 years. In 2008, 5.22 TWh of wind generation was wasted and the utilization factor was 71.5%, while in 2010, 23.86 TWh of wind power was curtailed, resulting in an average utilization factor of only 67.7%.

4. Possible explanations for decreasing utilization of wind farms

The main barrier for wind-power utilization in China is the inadequacy of the electric power grid. Among all the 44.7 GW of wind power capacity installed by the end of 2010, only 31.07 GW is connected to the grid [30], meaning that nearly one third of installed wind turbines cannot deliver their power output. Fig. 4 compares the installed capacity of wind farms with the capacity connected to the grid (termed "on-grid wind power"). It shows that as installed wind power capacity has increased, the percentage of wind generators connected to the grid has been declining steadily since 2006.

4.1. Policy omissions and failures

4.1.1. Inadequate financial incentives for transmission companies and providers of backup generation

Existing policies on wind power industry in China fail to balance the interests among all the stakeholders. According to the *Provisional Administrative Measure on Pricing and Cost Sharing for Renewable Energy Power Generation*, transmission companies should not incur any extra cost nor make excess profits from wind power integration. In reality, however, they do incur an extra cost due to the inherent intermittency of wind resources, as well as the fact that wind-generated electricity cannot be reliably dispatched or perfectly forecasted, which makes voltage regulation and frequency control more challenging [31,32]. To maintain system reliability in the presence of wind power, system operators need to plan for high and low wind generation by provisioning resources able to provide backup power, load-following, and regulation services.

The lack of economic incentives, coupled with the absence of policy enforcement mechanisms, has led to poor implementation of existing policies. The obligation for transmission companies to purchase all the electricity generated by registered wind farms has been stipulated in the *Renewable Energy Law* as well as other related regulations. Moreover, according to the *Wind Power Concession Program*, transmission companies are responsible for investing in the construction of transmission lines and the connection between wind farms and the nearest network [8,33]. Yet the rules are not being well abided because transmission companies are reluctant to build new grids connecting wind power plants to the main network, which results in a waste of installed wind capacity [9]. For example, due to delays in the construction of the necessary grid infrastructure, most of the wind farms in the Inner Mongolia Autonomous Region (IMAR) and Heilongjiang Province were forced to construct the transmission lines themselves [34].

The interests of coal-fired power plants, on the other hand, have also not been taken into account by the current policies. As mentioned earlier, a certain amount of back-up power sources should be kept for a reliable integration of wind power. In general, hydroelectric power and gas-fired power are the preferred alternatives for providing backup generation due to their load following capabilities. Unfortunately, gas-fired power capacity accounts for merely 2.7% of the total power capacity in China [7]; and the vast majority of hydropower stations are located in the southern area, far from the large wind power farms (see Fig. 5). This leads to coal-fired plants to provide backup for wind power integration.

Serving as backup forces the coal-fired power units to deviate from optimal operating points that are chosen to minimize cost [36] and maximize generation efficiency, thus reducing their own income [21]. But current policies on wind power fail to take these hidden system costs into account, and no reasonable compensation mechanism has been established for this particular dilemma [21]. It is ironic that coal-fired power plants are left in the position of having to help competing wind power get a higher market share, resulting in a distorted relationship between the two stakeholders and further prevents the optimal utilization of all resources in the power system.

4.1.2. Collaboration between local governments and large power corporations aggravates the imbalance between wind capacity and grid access

Local governments and large power corporations collaborate extensively in the development of renewable energy. As mentioned previously, a renewable portfolio standard in terms of installed capacity (not including hydroelectric power) has been imposed to large power enterprises with a total installed capacity of over 5 GW. In order to meet this standard and achieve the necessary levels to allow further increases to their conventional (coal, nuclear) power capacity, large state-owned power enterprises have hastened to exploit China's wind power market, and today hold more than 80% of the country's wind power installed capacity [21]. These corporations whose main business is thermal, hydro, and nuclear power but not wind power [8,17], obtain their participation in wind projects by promising provincial governments to support the local economy by using wind turbines produced by local enterprises as well as further investment in other fields.

Another problem stems from the wording of the *Decision of the State Council on Reforming the Investment System,* which stipulates that wind farms with a total installed capacity of 50 MW or more are subject to the approval of the NDRC, while smaller projects can be approved by competent investment departments of local governments [37]. This motivates local governments to split up large scale wind farms in order to keep the installed capacity of each project below 50 MW [38] which leaves the approval process

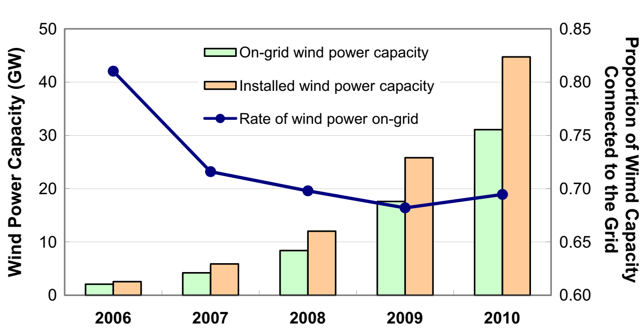

Fig. 4. Low ratio of wind capacity connected to the grid. Source: data from the Chinese Electricity Council [7,28], EBEPY [29] and CWEA [13].

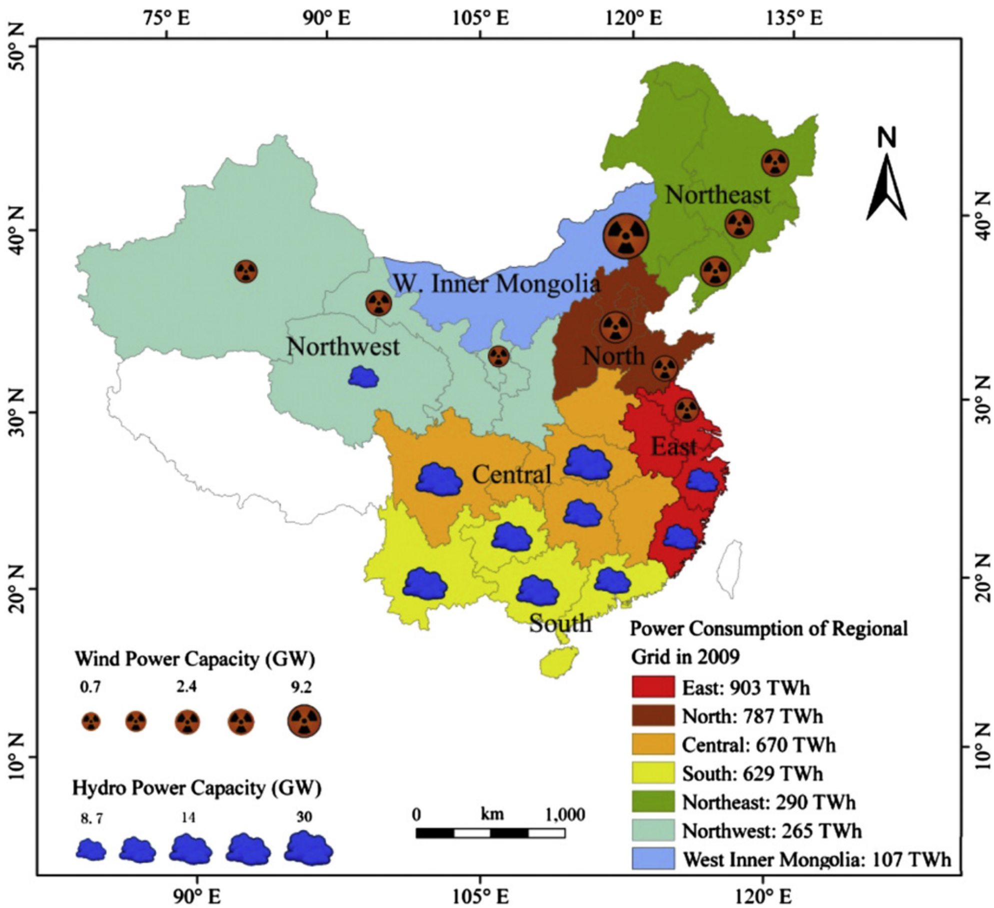

Fig. 5. Distribution of the 10 provinces holding the highest capacity of wind and hydro power as well as power consumption of regional grid in 2009. Source: data are from EBEPY (Editorial Board of the Electric Power Yearbook) (2010) [35].

in their hands bypassing the need for NDRC permission (and resulting in a phenomenon known as "49.5 MW"). This practice has contributed to the imbalance between wind power capacity and grid access [38].

The relationship between local governments and power corporations that collaborate on wind power projects is illustrated in Fig. 6.

4.1.3. Wind farms can be built faster than transmission lines

In China, as in the US, the time required to officially approve and build new transmission capacity is much longer than for new wind power plants. The reasons for this problem are twofold. First, the current approval process imposes strict requirements on the preliminary work of power grid projects. In order to obtain official approval, several supporting documents from the related government divisions including planning, land and environmental protection studies as well as an approved feasibility assessment are required [39]. Since most of the supporting documents are submitted and processed by government divisions at different levels, two to three years are usually needed only to get approval [40]. A much shorter time is required to officially approve a new wind power plant, especially to those wind farms with installed capacity less than 50 WM. On the other hand, the construction of transmission lines takes a longer time than the construction of wind power plants because it often involves land acquisitions and crop compensations to peasants -that many times scramble to plant new crops to increase their indemnifications- [41].

4.2. No advance planning of long-distance transmission lines

The best wind sites in China are often located far from its main load centers. Most of China's wind resources concentrate on the North, where relatively little power is demanded, while the significant electricity demand centers in the southeast have fewer

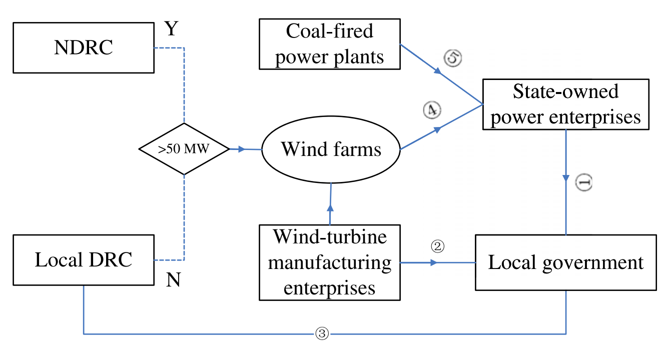

Fig. 6. Relationships of collaboration between local governments and huge power corporations. Arrows ① and ② denote the incentives that motivate local governments to approve wind power projects of 50 MW or less. The economic activity of state-owned power companies ① and local wind turbine manufacturers ② increases GDP, tax revenue, and jobs. Given these incentives, the local government authorizes the local Development and Reform Commission (DRC) to provide official approval of wind power projects with 50 MW or less of installed capacity ③. In this way, state-owned power enterprises get the wind power capacity required to meet the capacity-based RPS ④ and even achieve the necessary wind capacity required to build new coal-fired power plants ⑤.

wind resources as illustrated in Fig. 5. Therefore, long-distance transmission of wind generation from large-scale wind power farms to the load centers becomes necessary. However, this is not possible with the current transmission network due to its fragmentation. As shown in Fig. 5, China's physical grid is divided into four regional synchronous grids, with the Northeast-North-Central, East, and Northwest regions operated by the State Grid Corporation, and the South operated by the China Southern Power Grid Corporation [42]. Furthermore, Western Inner Mongolia owns a provincial grid operated by the government of IMAR. Although basic DC interconnection among regional grids was achieved in 2005, power flow among regions and even between provinces within regions remains limited [42].

The goal for wind power capacity by 2010 was set at 5 GW in the *Medium and Long-term Renewable Energy Development Plan*. Wind power at this scale can easily be distributed among the national grid system without the need to construct or update the infrastructure for long-distance transmission of wind power. However, the cumulative wind power capacity has surged up to 44.7 GW by the end of 2010, which is nearly nine times as the original target. Due to this unexpected expansion of wind power capacity coupled with insufficient transmission lines, wind power penetration in regional grid systems increased rapidly. For example, the Western Inner Mongolia Grid Company achieved an average of 11 percent wind power generation (peaking at a record 18.7 percent) during April 2010, far exceeding the safety limits of the local grid [43]. Consequently, most of existing wind farms are continuously curtailed by transmission companies seeking to ensure reliability of the local grid system.

5. Conclusions and policy implications

With the goal of solving severe energy and environmental problems, the Chinese government has made great efforts in promoting the development of wind power. Since 2005, when the *Renewable Energy Law* was promulgated, annual cumulative wind power capacity in China has more than doubled for five years in a row, and it is predicted to continue with its rapid development in the future. Abundant wind resources, relatively mature technologies, declining capital costs [44], a favorable market environment, and a system of policy incentives have made this increase in capacity possible. However, growing installed capacity alone is no reason to be optimistic about the status of electricity from renewable sources in China. The average capacity factor of wind power in China during 2007–2010 was merely 16.3%, far lower than that of the US and some European countries. This is due to a decline in the utilization factor of existing farms.

We conclude that the main reasons why wind generation remains low in China are the lack of economic incentives to provide backup generation necessary for wind power integration and the inadequacy of the power transmission grid. Several measures should be taken in order to remove these obstacles of integrating a larger share of wind power generation. First, in order to stimulate wind power integration, attractive financial incentives should be set up for grid system operators and back-up power sources. Second, since both the *Renewable Energy Law* and other related regulations failed to solve the problem of wind power integration, a rigorous monitoring system with fines and financial incentives should be set up to force the implementation of existing rules. Finally, a mandatory RPS in terms of generation rather than installed capacity should be imposed both on the large power enterprises and grid companies.

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