China´s Wind Power Development – An Anatomy of Mishaps

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Abstract

China has in recent decades expanded its wind power generation capacity and become the world leader. Still, despite robust government support, wind power in China is obstructed by various barriers (e.g. quality deficiencies, inability to export, missing grid connections, and permit delays from central government for grid construction etc.). This paper synthesises the literature that has discovered weaknesses in the Chinese wind power development and suggests improvements. One energy policy relevant observation is that when the Chinese government sets command-and-control construction targets over new installed capacity, actors delivered to target – but with several power plants without grid connectivity and severe quality problems. The article contributes to the academic debate over the role of policy making in renewable energy development and argues that China should improve their incentive structure and coordination of regulations.

Keywords: China, Wind power, Generation, Policy, Energy, Innovation.

JEL classification: O11, O21, O53, P18.

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1. Introduction

There is an increasing interest in the transformation of the Chinese energy system, where the cumulative capacity increase has led to many calling China the leading wind power country in the world (Zeng et al., 2015; Lam et al., 2017; Karltorp et al., 2017; Sahu, 2017). By the end of 2016, the total cumulative installed capacity of wind power in China achieved 168.7 GW, 34.7% of global installed capacity. The overall capacity of all wind turbines installed worldwide by the end of 2017 reached 539,2 Megawatt (WWEA, 2018). Globally 52,5 Megawatts were added in the year 2017 constituting an annual growth rate of 10.8%, of which China added 19 Gigawatts. China continues its undisputed position as the world's wind power construction frontrunner, with a cumulated wind capacity of 188 Gigawatts in 2017 (WWEA, 2018).[1]

However, whilst China has been successful in expanding generating capacity, the country has not managed, as will be shown in this paper, to become a significant technology developer, much less a leader (Feng et al, 2015; Zhang et al., 2017).[2] China has previously been criticized for adhering to a capacity building rather than capacity utilization strategy, namely with a capacity-based goal, rather than a power generation-based goal in planning (Shi, 2008; Li et al., 2018).

The purpose of this paper is to synthesise the literature that has documented weaknesses in the Chinese wind power development and from these weaknesses suggest improvements. Hence, this paper aims to answer the question: *which mistakes occurred in Chin´s recent wind energy expansion development?* There is no doubt that China has made an extraordinary expansion of its wind power capacity — so the identified mistakes could be useful for policy makers in other countries that are beginning a transition to large scale sustainable energy utilization.[3]

The literature indicates many failures in the Chinese expansion effort (see e.g., Karltorp et al., 2017; Zeng et al., 2015). Despite robust government support, wind power in China is obstructed by various barriers (e.g. quality deficiency's, missing grid connections, two-year permit delays from central government for grid construction etc.) and provided only 2.6% of national electricity generation in 2016 (Junfeng et al., 2002; Zhao et al., 2016; Liao, 2016; Sahu, 2017). These failures have reduced the efficiency and effectiveness of China's wind power development with consequences such as very low potential for export and less energy output than otherwise possible (Zhang et al., 2015; Sun et al., 2015). Several other problems have also been revealed such as low operational efficiency of wind farms (Han et al., 2009; Xingang et al., 2012; Luo, Tang and Wei, 2016).

1 The other leading markets also added significant new capacity: the US (6,8 Gigawatts added, reaching 89 Gigawatts in total), Germany (6,1 Gigawatts new, overall 56 Gigawatts), India (4,6 Gigawatts added, 32,9 Gigawatt total capacity) United Kingdom (3,3 Gigawatt new, 17,9 Gigawatt total), Brazil (2 Gigawatts new, 12,8 Gigawatts total) and France (1,7 Gigawatts new, 13,8 Gigawatts total) (WWEA, 2018).

2 Consequently, the installed capacity is less effective than it would have been if the technological level was higher, but China will also for an unforeseeable future have a hard time exporting wind power product (Sun et al., 2015; Zhang et al., 2015).

3 Problems are continuously dealt with and new efforts are made (see e.g., Zhang et al., 2018)

Zhang et al., (2013) holds that the failure (in terms of lower target achievements than otherwise possible) of China’s wind power development lies within institutional sources steaming from political decision making. Zhang et al. (2013) found that there are two prominent policy failures in China’s wind power development, specifically the low proportion of grid-connected capacity and the rising trend of wind turbine incidents (see also Zhe, 2011; Sun et al., 2015; Zeng et al., 2015; Zhang et al., 2017).[4] The first policy failure resides in the political preference for setting wind power development targets in terms of installed capacity rather than generation. Further, a coordination problem is identified, where the second policy failure lies in the lack of state technical codes for wind power integration and the unfair competition from the large state-owned power companies. Furthermore, there have been periods of slowdowns due to unintended policy effects that have caused financial constraints felt throughout the Chinese wind power technological chain (Liu et al., 2015; Karltorp et al., 2017).

The remainder of the paper is organized as follows. Section 2 gives context and introduces China´s wind power development. Section 3 presents a selection of identified problems in the Chinese wind power development system, whilst section 4 provides a discussion on workable improvements to be made, whilst Section 5 contains the conclusions and policy implications.

2. The context

As presented in the introduction, the Chinese expansion of installed capacity is globally the largest (Zhang et al., 2017). However, as argued in this paper, there are several areas where the development is underwhelming. The main issue is the cases of underutilisation of the power generation in the expanded capacity. There is a large variance between installed capacity and given electricity generation (figure 1 and 2).

2.1 Large but inefficient expansion of capacity

In the 1970s, wind power projects in China were limited to small off-grid applications in remote areas (Liu et al., 2002; Xu et al., 2010). The early development of grid-connected wind power in China started from the late 1980s, when four 55 kW Vestas turbines were imported from Denmark in 1985 and deployed in Rongcheng in Shandong province (Zhengming et al., 2006). China’s early build-up of renewable energy was facilitated by government finance and funding from international agencies, like the World Bank, UNEP and Asian Development Bank, supplementing bi-lateral agreements (Liu et al., 2002).

In 1994, one of China’s first wind power specific policy was introduced when the Ministry of Electric Power (MOEP) set a hundred-fold installed capacity increase as target, from about 10 MW in 1993 to 1000 MW in 2000, the target was not reached and ended up being just 350 MW. To support these targets the government obliged utilities to buy (or produce) electricity

4 As highlighted by Zhao et al., (2012), in 2010, China’s grid connected installed capacity was only 31,000 MW, which means about 30% of China’s total installed capacity could not at that point in time access the grid. However, Xu et al., (2010) points to the fact that in the early Chinese wind power history (1975 – 1985) most power plants were small off grid installations for farms, herders and fishermen. These were however <10 kW installations.

from wind power and introduced a price guarantee to developers of 15 percent above construction cost (Lema and Ruby, 2007). However, both these policy measures failed since they did not achieve legal status and hence contempt could not be penalised. And contempt there was, which was not unsuspected due to the fact that the wind energy was significantly more expensive than coal power (Lema and Ruby, 2007; Karltorp et al., 2017). Up until the year 2005, wind power in China experienced unhurried development. By the end of 2004, accumulated installed wind capacity was a mere 769 MW, ranking tenth in the world wind power market (Zhang et al., 2013).

During China´s "Eleventh Five-Year Plan" period (2006-2010), wind power installed capacity doubled for five consecutive years; making China the world's largest country in terms of wind power installation capacity, where four wind turbine equipment manufacturers entered the world's top 10 (Sun et al., 2015).[5] Around 2012 China bypassed USA as the country with most installed capacity (see Figure 1).[6]

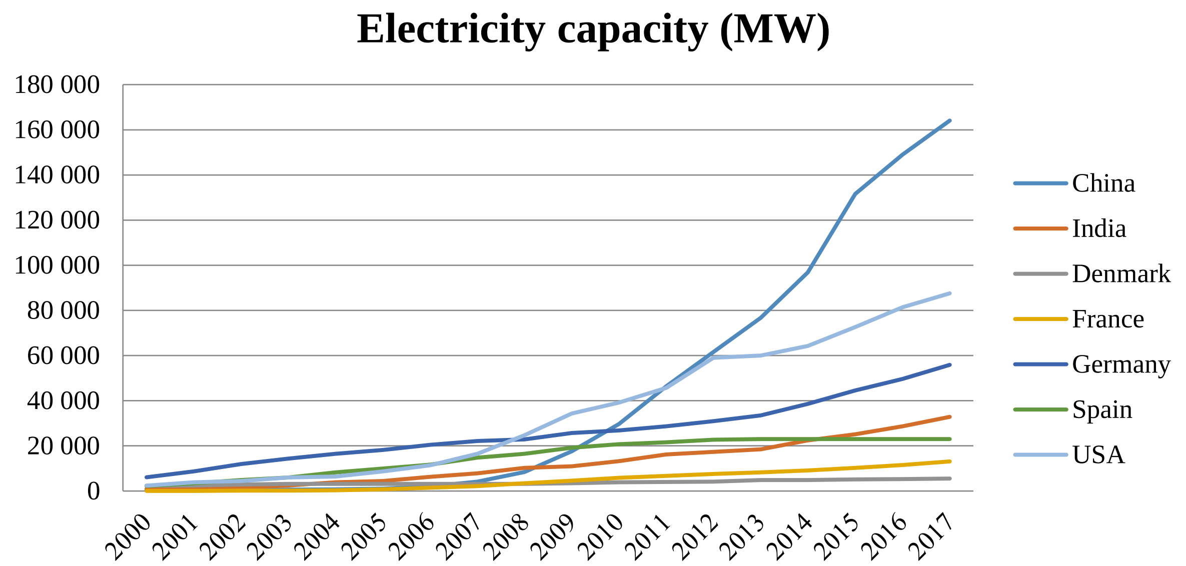

Figure 1 Electricity generation in wind power by country from 2000 – 2017. Source: IRENA (2018), Renewable Energy Statistics 2018, The International Renewable Energy Agency, Abu Dhabi.

5 China have also issued a series of policies to promote the development of wind power, such as fixed price, investment subsidies, tariff incentives, tax exemption, domestic rate requirements, export assistance programs, research and development (R&D) support, green electricity, renewable energy quota system, concession policy and certification policy (Li et al., 2018).

6 For off-shore wind power, China still has a problem with both a weak technical support system and underdeveloped technologies (Zhang et al., 2018). This paper will focus on on-shore wind power which at the moment outnumber off-shore wind power with almost a factor of 100:1.

However, when it comes to electricity generation the US was for a long time significantly higher, even though the Chinese installed generation capacity was almost double – the electricity output was almost equal (See figure 2). As will be discussed in the papers there are some reasons for this but no satisfying overall explanation.

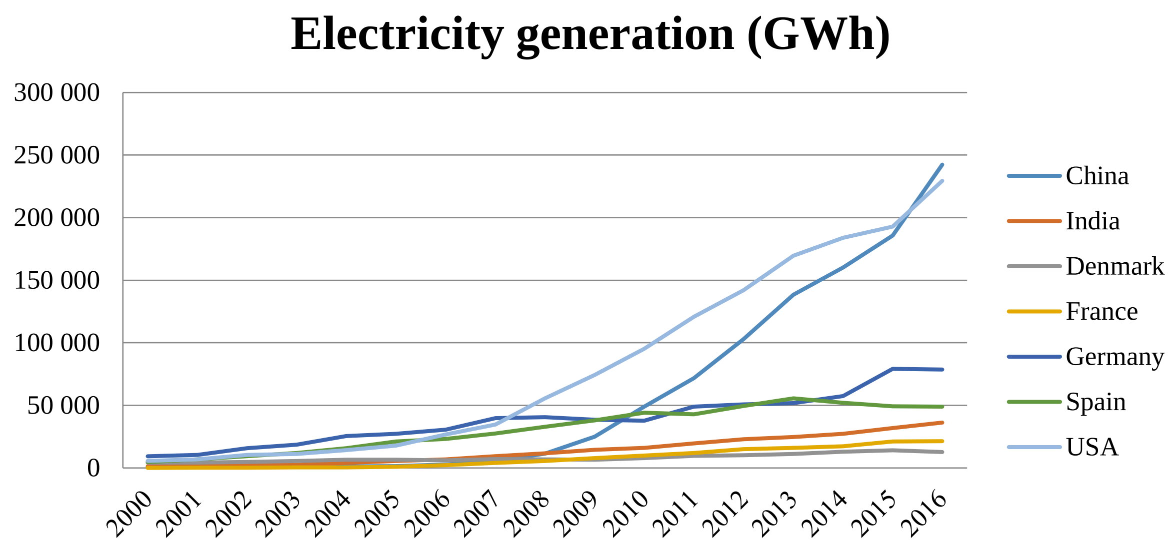

Figure 2 Electricity generation in wind power by country from 2000 – 2016. Source: IRENA (2018), Renewable Energy Statistics 2018, The International Renewable Energy Agency, Abu Dhabi.

3. Identifying problems

The review of previous academic research describing the development of the Chinese wind power development several criticisms are identified and these downsides will now be highlighted. In order to construct an outline for the literature synthesis, we have organized this research into the following categories: (a) *Conflicting policies – leading to unintended consequences*; (b) *China has insufficient transmission grid systems*; (c) *Quality and curtailment problems*; and (d) *Lacking technological standards*.

3.1 Conflicting policies – leading to unintended consequences

China´s Governmental policies have been conflicting with several of actors issuing policies for wind power (Lema and Ruby, 2007). Liao (2016) studied 72 wind energy policies issued between 1995–2014 and showed that the number and stringency of wind energy policies fluctuated greatly with more than twenty actors that independently or jointly issued the policies. Issuers of policy was predominantly the department that controlled key economic and administrative resources – not the one that oversaw wind energy. For example, the pathway from one predominant wind power project form to another creates an illuminating backdrop for a synthesis of several of the problems previously described in the introduction – the move from government contract projects to concession projects.

Government contract projects appeared in the early 1980s, whilst the first concession project was carried out in 2003 (Han et al., 2009). Approval of government contract projects worked as follows: wind power companies presented project proposals to the National Development and Reform Commission (NDRC) or in smaller applications (in terms of MW) to a local administration such as Inner Mongolia Development and Reform Commission (IMDRC). For projects larger than 50MW, the NDRC were responsible for decision-making; whilst the IMDRC, local counterpart of NDRC, could approve projects smaller than 50MW without approval from NDRC. Initially the conditions in the power sector remained unclear without, formal protection of new investors, private investment failed to materialize (Lema et al., 2007).

The separation of project approval reduced bureaucracy because previously every new project needed approval by NDRC, which made the application for wind power projects complex and time consuming. However, since provincial governments could approve projects below 50 MW a substantial number of wind farms became 49.5MW in size. These smaller local installations were not coordinated with development of grids managed by central authorities rendering grid problems (Zhang et al., 2013; Karltorp et al., 2017). Lema and Ruby, (2007) holds that the contradictory policy measures are due to lack of coordination between different authorities, for example at central and provincial levels and that the period 1994 to 2001 was characterised by fragmented and sometimes conflicting policies from different levels of government.

The later concession model opened the market, and to some extent formed a market, but with weaknesses (Lema and Ruby, 2007). The utilities/firms who offered the best price per kWh on the terms provided won the concession and consequently the right to construct wind power plants and produce electricity on the concession site. The winner was guaranteed a fixed price throughout the first 30000 full load hours (power purchase agreements; PPA). After the initial 30000 full load hours period and until the end of the concession period, electricity would be sold at a uniform on-grid price.

The concession model has unintended and with hindsight obvious disadvantages. First of all, some bidders had incentives to intentionally underestimate operating costs to get a lower power price compared to other bidders.[7] Large power companies in China were obligated (renewable energy portfolio standards due to the Renewable Energy Law of 2006) to have a certain amount of generation capacity of renewable energy sources, with emphasis on capacity not output.[8]

The new policies had a profound impact on the market. The combination of the renewable portfolio standard and the concession programme initiated a steep fall in the prices of the winning bids (between 30-50%) since the domestic firms needed the output and could finance it with their much cheaper coal subsidiary (i.e., utility's made unprofitable bids using

7 Some of the weaknesses were later taken care of by eliminating the lowest and highest bids.

8 Large state-owned utilities had to have an installed capacity of 3% non-hydro renewable energy by 2010 and 8% by 2020 (Gosens and Lu, 2013). The motivation was to incentivize grid operators to buy wind generated electricity.

cashflow from other business areas enabling them to develop unprofitable projects). Intense price competition hampered technology improvement and quality assurance (Hayashi et al., 2018). Foreign companies were driven out of the market since they could not compete at these price levels (Klagge et al., 2012). Hence, an important source for know-how and technology transference was cut off.

The exit of foreign firms was further enhanced by a pre-requisite in the power purchase agreements (PPA) which stipulated that there should be 50 percent local content (later 70 %) in the wind turbines. Whilst, approximately 95% of the turbines installed in China up to 2000 were imported, the following decades saw a significant drop. In 2005, more than 70% of China's wind power equipment was imported. In 2008, domestic manufacturers covered 72% of demand and by the end of 2013 domestic manufacturing levels had reached 94% (Liu et al., 2015; Zhang et al., 2015). The policy goal of the domestic production of wind power was well fulfilled but led to problems. An overcapacity was generated which caused price pressure (for the wind power expansion, not a bad thing), in 2011, the manufacturing capacity was 30 GW, but the annual demand was only 18 GW (Li et al., 2012; Zhang et al., 2015).

Another problem was financial delays as coming from the bureaucratic nature of the renewable energy subsidy scheme leads to financial constraint problems along the whole development line (Karltorp et al., 2017). The Electricity end - users were obliged to pay a surcharge for renewable electricity which showed up on their energy bill. The payment went into a fund under the ministry of Finance, which then redistributed the money to the provincial Finance Bureau. From there the money was distributed to local utilities based on their renewable energy production. For the firms a hampering issue was that the payments were slow to reach them (Sahu, 2017). It took two to three years before the payments finally reached the utilities. The utilities then had problems paying the turbine manufacturers who in turn could not pay the component providers. As the subsidies were up to half the selling price of electricity the two to three-year payment delay caused severe problems for the firms.

3.2 China has insufficient transmission grid systems

Despite an accelerated growth of installed wind power capacity over time, grid-connected capacity of wind power has lagged behind installed capacity by more than 30% in some time periods which is higher than the 10% gap in developed countries (Zhe, 2011).[9] In some geographical areas, wind power generation exceeded the acceptance of grid scale – leading to wind abandonment and a systemwide negative effect on grid stability (Sun et al., 2015; Zeng et al., 2015). Hence, a significant amount of renewable generation capacity is wasted because of lacking electricity grid connection (Zhang et al., 2017).

Energy production and consumption is geographically mismatched, and the wind power construction is faster than the growth of the local power accommodation capacity (Fan et al., 2015). China's wind energy resource-rich regions are largely situated at the end of the power

[9] Some grid operations are natural, e.g., lone farms or villages. However, when the wind power plants grow larger and produce an overcapacity, it is natural to off-load excess energy on the grid if possible, since there are economic incentives to do so.

grid in the northern non-populated areas, where the power grid structure is not strong enough and large-scale wind power puts pressure on the stability of the power system (Han et al., 2009). The Chinese government have been slow to implement effective incentive policies for large-scale and long-distance wind power transmission. Grid expansion is costly for power companies and upgrading the power grid can be even more costly. Even though the concession project policies state that ‘‘the power grid company will construct a transmission line to the wind farm’’, there are potential loop-holes regarding the time the construction should be finished or the standard of transmission line (Han et al., 2009).

A wind power-based system is a sensitive power system compared to most of the baseload systems. Wind power worldwide regularly requires integration system technical standards. With requirements for wind farms or wind turbines to have dynamic reactive power regulation ability, active power set-point control ability, active regulation ability and low voltage ride through ability on grid networks special occasions (Sun et al., 2015). These requirements grow in importance in a power system with a high wind power proportion, these abilities are important to large scale wind power integration. China lacks such abilities (Xingang et al., 2012). The lack of technical standards leads to wind machine manufacturing enterprises losing incentives to increase manufacturing costs to produce quality and grid friendly wind turbines.

3.3 Quality and curtailment problems

China´s early phase focus on quantitative expansion led to limited technological knowledge development leading to an accumulation of problems later.[10] The low-quality power plants affected the financial situation for turbine manufacturers, who had to spend an increasing amount on maintenance and repair of installed turbines (Karltorp et al., 2017). The grid was also affected by the poor quality of turbines (Sahu, 2017). China faces a worrying phenomenon “wind curtailment”[11] in the development and operation of the wind power industry leading to a sharp decline in the utilization rate of the wind power plants (Sun et al., 2015; Fan et al., 2015; Zeng et al., 2015; Luo et al., 2016).

The curtailed wind power was, according to Luo et al., (2016), estimated to be, over the time period 2010 to 2013 around 3.9 TW h, 10 TW h, 20.8 TW h and 16.2 TW h, respectively.[12] The consequence from the usage drop, compared to the planned capacity, has been large economic cost due to the curtailment rate of 10.20 percent. Since 2011, the industry growth was slowing down; and there was a frequent occurrence of large-scale wind turbine tripping in the first half of 2011 (Liu et al., 2015). The rapid installation of new wind turbine capacity, without proper maintenance and management technologies, compromised safe operation (Feng et al., 2015).

10 Regarding the failures, most wind turbine failures are due to the following component failures: frequency converters, generators, gearboxes, pitch systems, yaw systems, blades and braking systems.

11 Wind curtailment mainly refers to the wind power not being put on grid and then wind turbines must be shut down because of the safety, technology, grid access management, system and other reasons.

[12] Large-scale wind power grid accommodation has always been a worldwide problem, yet the problem is more prominent in China (Fan et al., 2015).

Between 2011-2015 the curtailment rate in the country was 15 % (Zhang, 2016). The overall operation losses were in 2012 about half of the revenues of wind farms (Karltorp et al., 2017). The curtailment rate has also been going up by 10 percent the last six years (Sahu, 2017). In 2007 the national average full load hours of wind turbines was (1787 h), which is considerably lower than that in western countries such as United Kingdom (2628 h), Australia (2500 h) and United States (2300 h). There were (extreme) cases of turbines which were designed for 2000 full load hours in operation for only 300h a year.

From a technological perspective Lin et al., (2016) identified four primary reasons for the operating failures: lack of core technologies; inferior quality due to price competition; design standards and wind farm climate differences; and no mandatory quality certification and exterior factors, such as wind farm construction, power grids and maintenance. Besides technical deficiency reasons, some researchers also ascribe the problem of low utilization to the prevailing policy system where the focus is on installed capacity rather than actual utilization of wind resource (Shi, 2008; Li et al., 2018).

3.4 Underwhelming technological development

The technological development has been is surprisingly underwhelming (figure 3 and 4). In section 3 more direct problems are highlighted (such as low exports and quality problems). Previous literature has identified that an expansion of wind power installation often has positive spillovers on wind power technological development in the country (see e.g., Grafström and Lindman, 2017; Grafström 2017). [13] In terms of innovation and competitiveness outcomes China has had limited international success (Lam et al., 2017). Chinese wind turbine manufacturers have secured few international patents and several major manufacturers have not been able to patent at all.

For example, patent applications to the European Patent Office (EPO) were abysmal (between 1980 and 2014). The two major Chinese firms who tried to patent – Envision and XEMC – had respectively lodged 38 and 19 EPO applications, being granted respectively two and six patents. The firm Sinovel submitted 21 patent applications to the EPO, of these; all but one (who was granted) was either subsequently withdrawn by Sinovel or deemed to be withdrawn by the EPO. Among the top 10 manufacturing firms seven obtained no EPO patents, and five of them have no recorded applications through EPO. The success and application rates were similar at the USPTO.

There are of course legitimate reasons why a firm chooses not to patent: For example, the Chinese exports have been very small within the wind power field (Sun et al., 2015). Chinese producers have no particular reason to not patent, a producer stands to lose money if another producer is free to imitate that technology. Without Chinese firms' patent protection their inventions in said jurisdictions, cannot prevent foreign inventors from infringing on their intellectual property rights. Lin and Chen (2018) attributed the lack of innovation in renewable energy technologies to the late commencement of renewable energy in China.

[13] Or Grafström (2018a) and Grafström (2018b).

Zhang et al., (2017) states that China's weakness in wind power innovation is problematic, implicating that most key wind power technologies need to be imported from abroad since domestic enterprises lack the ability for innovation and independent R&D. In figure 3 the distribution of patents taken out in the wind power sector amongst seven of the top technological countries in the sector are displayed.[14] Figure 3 starts with the proportion (between a selection of wind power patents that each respective country has where the patent has been approved at least one patent office.

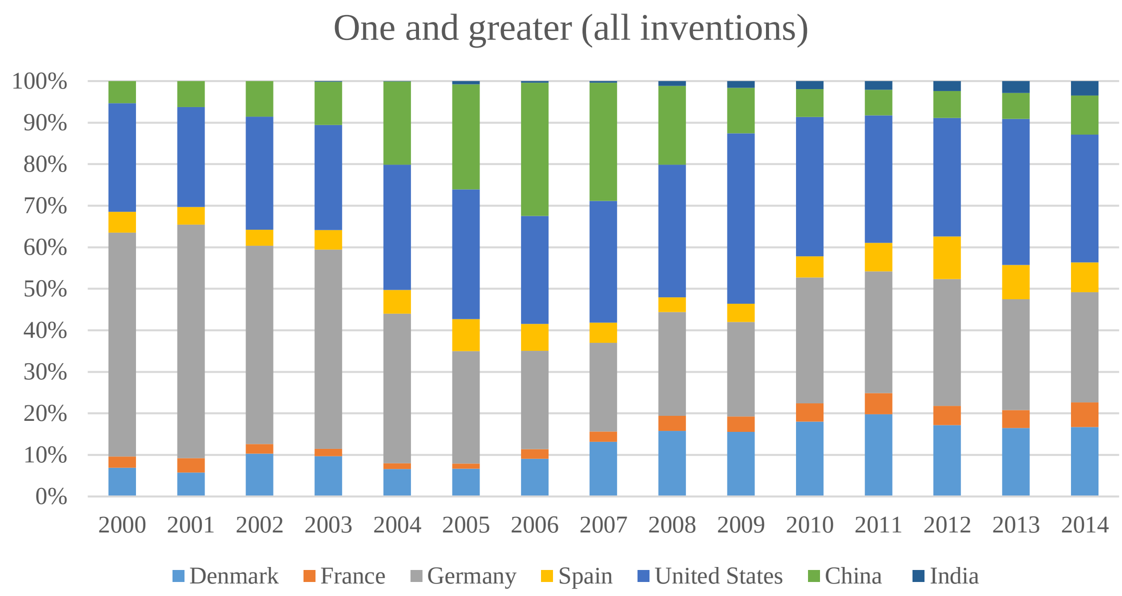

Figure 3 Patents proportion by country awarded to one patent office or more. Source: OECD.stat Dataset: Patents - Technology development.

Only observing one single patent office (most likely the home country office for each respective country) is not an optimal comparison case since the different local offices can have criteria with differing degrees of strictness. What we observe is that the Chinese patent activity was large around 2006 but only if we consider the first graph. If we observe figure 4, were the patent must be approved at more than one office (i.e.., an indicator of a higher quality patent) then the Chinese patents are absent. Before 2009 Chinese patent examiners

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14 The justification of looking at patents as a proxy for innovation lies in its comparability across the globe; when using a patent count from one or more international sources such as the WIPO, SIPO or European patent office. Patents have an internationally standardized format and it is by no means easy to get a patent application approved: fundamentally, the inventor has to disclose to the public something that is 'novel', 'useful', and 'non-obvious', and that has an inventive step to obtain a patent (Griliches 1987; Hall and Ziedonis, 2001).

It is probable that not all innovations in the wind power industry are patented. However, the end products, like power installations, are indeed quasi-public goods, thus suggesting that there is some accessibility to production information that enables the reverse-engineering of parts. Another reason why a patent is not applied for, may be that small firms find the application process difficult; as a result, they may not bother submitting an application (Adams, 2005). Instead, firms will employ various types of secrecy to veil their production methods (Cohen et al., 2000; Trajtenberg, 2001).

Nonetheless, even with all their potential flaws, patenting records remain a good – possibly even the best – available quantitative source for assessing technological changes and innovation. As Griliches (1998, 336) puts it, 'nothing else comes close in quantity of available data, accessibility and the potential industrial organizational and technological details'.

limited their search reports to only domestic prior art, thus no report for absolute global novelty (Cass, 2009).

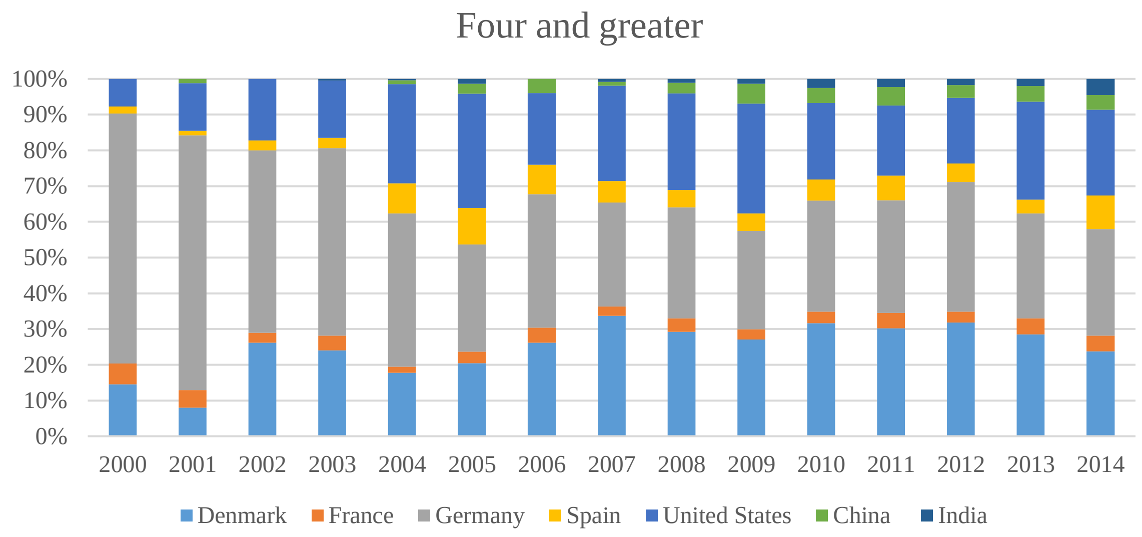

Figure 4 Patents proportion by country awarded to four or more patent offices. Source: OECD.stat Dataset: Patents - Technology development.

It is likely that Chinese patents were of lower quality and it was easier to obtain a patent grant in China in the earlier part of the 2000s and hence a side-by-side comparison is unproductive.[15] However, in 2009 China initiated quality increasing efforts by amending its patent law to require absolute global novelty instead of 'relative novelty' (SIPO 2009). The amended patent law should reduce the quality gap between Chinese and foreign (e.g. EPO, USPTO) authorized patents and the gap should be closing after that year. Below the absolute numbers are displayed.

Table 1 Absolute number of patents registered at one or more patent office. Source: OECD.stat Dataset: Patents - Technology development.

One office registration	China	Germany	USA	Denmark	Spain	France	India
Patent in 2000	12	121	58,67	15,5	11,17	6	0
Patent in 2009	174,2	361,17	652,03	247,25	69,83	59,42	26,28
Patent in 2014	96,17	270,17	313,83	170,83	73,83	60,83	35,33

15 An important consideration regarding patent data is using the geographical location of the inventor rather than that of the formal applicant. The applicant (e.g., a firm) can be an entity registered in a locality that is not the same as where the knowledge was actually produced (e.g., Fischer et al., 2006). Some patents are awarded to multiple inventors; when they are from different countries in such cases, the count has been split. Furthermore, the researcher needs to choose whether to look at only granted patents or whether to include all patent applications. For example, in the EPO only around half of all patent applications are finally granted: many are rejected because they lack novelty or are unable to meet other set requirements (Battistelli, 2011).

Table 2 Absolute number of patents registered at four or more patent office. Source: OECD.stat Dataset: Patents - Technology development.

Four office registration	China	Germany	USA	Denmark	Spain	France	India
Patent in 2000	0	36	4	7,5	1	3	0
Patent in 2009	12	123,5	108,42	121,58	22	12,58	6,28
Patent in 2014	8,33	59,83	48,17	47,67	19	8,83	9

For a long time, there were a growing number of domestic patents taken. Lei et al., (2013) and Li (2012) explained the surge with different governmental programs (institutional changes) that were aimed at increasing the number of patents. Chinese companies were incentivised to take local patents. On the topic, Gosens and Lu (2013; 2014) also pointed at that granted patents were an evaluation criterion for many in the government and in private research institutes. The Chinese legal system also had problems with separating real innovations from false innovations. Hence, there was a large amount of "junk" patents in the data (Lam et al., 2017).

3.5 Lacking technological standards

Two decades ago, the majority of Chinese wind energy equipment was principally imported goods. During the 11th five-year plan (2006–2010), efforts were made to advance the domestic wind power system and their related components (Feng et al., 2015). The wind power equipment market share of the domestic firms increased from 25% in 2004 to 87% in 2009 (Junfeng et al., 2010). In 2012 there were only two (Gamesa and Vestas) international firms in the top ten lists of the manufacturing parts, accounting for 3.8% and 3.2%, respectively (Feng et al., 2015).

However, the markets of advanced components such as bearings, converters and control systems were still dominated by international companies. The absence of domestic production capability generated a sizable supply–demand gap for above MW core parts placing manufacturers at a technology import-absorption stage without their own key technologies (Xingang et al., 2012). Up to 2013 the domestic Chinese manufacturers of turbines were falling behind noticeably compared to international competitors where the Chinese companies did not master the construction of larger power plants (Liu et al., 2015).

A key weakness with the Chinese wind power is, at present, that several equipment products cannot be integrated in a large-scale grid. A lack of technical standards is described as a main reason where wind machine manufacturing enterprises do not have incentives to increase manufacturing costs to product more high performance and more grid friendly wind turbines

(Xingang et al., 2012; Luo et al., 2016).[16] The accumulated exports of wind turbines were between 2011 to 2014 a total of 1.7 GW to the U.S., South American, and European countries (CWEA, 2015). In 2013 the domestic new installed capacity was16088 MW whilst the exports were 692 MW, i.e., around 4 % of domestic installation (Liu et al., 2015).

Whilst the Chinese wind power industry expanded in recent years, the control technology and other technological aspects were not given enough attention in the early years leading to problems in the long run.[17] In the early period many Chinese wind power companies began operation by purchasing drawings from international giants, but they disregarded the importance of full assimilation of the core technologies. The rapid installation of the undigested wind turbines has led to deficiencies in maintenance and management technologies, causing instability of operation and many quality accidents. China's wind farm construction speed could according to Sun et al., (2015) be progressing too fast for now, with a lacking technical standard system combined with an industrial chain whose standards are sub-par. Furthermore, the incentive structure incentivises some wind power firms to only cost-minimize, generating poor quality wind turbine products and projects that do not meet Chinese or international standards.

One technologically related issue is that the turbine and system testing capabilities in the Chinese wind power industry have been lacking (Zeng et al., 2015). A bad electricity performance by the wind turbines creates potential security risks in the power system. The larger the scale of the connected wind power system gets the more important the controllability is to ensure the security and stability of the power system. Over the last decades a large portion of the wind turbines operating and connected to the grid have lacked testing certification and do not meet the technical requirements to be connected to grid. One big problem occurs when turbines without the capability of low-voltage ride disconnect from the power system when a system occurrence transpires, this problem leads to a secondary shock due to a decreasing amount of power which in turn might spill over in other parts of the system.

According to Lin et al., (2016), when it comes to technological standards, there are some relevant explanations why the Chinese standards are not aligned to international standards. The design standards of China's wind turbines are the Wind Turbine Specifications released by the China Classification Society in 2008 and are based on IEC61400-1(2005) and the Guideline for the Certification of Wind Turbines by Germanischer Lloyd. The IEC standard is not perfectly suitable for the Chinese climate and is based on the European climate. In China there are other parameters to consider and European parameters deviate from the Chinese rather extensively in terms of altitude, extreme temperature, humidity and other environmental factors. For example, the wind regime in China is characterized by a gustier wind with higher intensity. The average turbulence intensity is approximately 58 to 156%

16 Other recognized problems are a lack of the large-scale market requirement, and lack of advanced technology and equipment. However, there has been a gradually reduction of these problems since 2010.

17 The wind power control system market in China is still to some extent in recent years dominated by international overall solution providers such as American Superconductor (AMSC), Denmark DEIF Wind Power Technology, and Denmark Mita-Tekni (Feng et al., 2015).

higher in China. Furthermore, there is a typhoon season to consider for the southern part of the country. Whilst north-eastern China's temperature is 15–20° lower than the average temperature in the latitude and the summers are amongst the warmest in the same latitude.

4. Discussion - Workable improvements to be made for the Chinese wind power development

The Chinese wind power industry faces barriers that are like a hydra, if one head is dispatched another one takes its place. There are institutional, managerial, technological, and cultural obstacles, and to develop effective policy to alleviate these, the interrelationships between them needs to be understood. When analysing undesirable policy results an economist usually resolves to examine the incentive structure. So, what explains China's lacklustre results? The short answer is that the wind power sector delivers in line with incentives.

The existing Chinese power sector is still profoundly regulated by administrative practices and planning, which seems to be the predominately underlying institutional reason for the challenges described. From an economically theoretical perspective, a well-established electricity market could provide practical solutions to some of these challenges since the incentives could be more in line with the intended goals of deploying and using renewable energy.

A supplementary market-oriented trading system (an ongoing reform process that has started) over regional boarders would be helpful to balance the power system. There has been intervention from local governments in direct electricity trades where local governments have an incentive to reduce energy prices as much as possible to stimulate the local economy whilst that might not be beneficial for the power system (Zhang et al., 2018).

The application of administrative rather than economic mechanisms in different areas that are important for the energy sector has been described as a major hurdle for a well-functioning energy system (Depuy, 2015). It is problematic that pricing for both wholesale and retail power remains under the control of the central government, since the central government has failed to deliver incentives for flexibility on the part of generators and end-users. The influence of provincial governments over the power system is believed to hinder the interprovincial electricity trading (Pollitt et al., 2017).

There is room for several reforms including the central government strengthening top-level design and supervision, design and build up electricity spot markets, push forward the regional electricity markets. The interests between, state, grid operators and wind power development must be balanced. Currently, the incentives for grid operators to incorporate wind power to their grids is small, due to delivery security problems.

The Chinese problem is double edge, where both more and less planning is needed. Zhang et al., (2017) concluded that the current policies and regulations are not suitable for China's current renewable energy transition situation. There are problems with management, strategies, programmes and policies which are sorted and separated under too many departments of the Chinese central- and local government, generating several policy conflicts. No plan survives first contact with reality and following Nobel prize winner Hayek's article

"The Use of Knowledge in Society" (1945) it is evident that a central plan will face obstacles. Drawing from Hayek, we can assert that a centrally planned wind power program in many instances does not match the efficiency of the market because the incentives and the knowledge and imagination of a single planning agent is only a small fraction of the total sum of knowledge held by all members of society.

If policies should be implemented – they should be matched to the policy goal – for example, the goal of constructing power plant capacity (with mandatory portfolios) leads to construction (i.e., generation capacity) but not necessarily generation of energy. The incentives promoted construction – no matter if the construction could be connected to a grid or be economically profitable. Hence (assuming generation of clean energy is the variable to optimize), more market-oriented policies are called for such as making it more profitable to produce wind power (e.g., by feed-in-tariffs or taxes on coal) thereby generating incentives for energy production – not merely construction.

5. Concluding Remarks and Recommendations

China has made remarkable achievements in development of wind power. However, and there is a big however, it is undeniable that there has been a problem for China's wind power industry since the very beginning. The identified Chinese problems are energy policy learning opportunities for both other countries and for China in the future development new technological fields.

The purpose of this paper was to synthesise the literature that has discovered weaknesses in the Chinese wind power development and from these weaknesses suggest improvements. We must conclude that there are weaknesses in the Chinese system and much room for improvements. Examples are incentive issues when it comes to connect wind power plants to the grid, both from grid companies and also to some extent from the energy producing companies. A rapid expansion with an aim of low costs has led to quality problems and reduced the possibility to export power plants, even though there has from time to time been a substantial overproduction.

It was not clear a priori whether there were a significant amount of failures justifying calling out the failures as systemic, but the evidence points to a string of policy mistakes that offers learning. The existing Chinese power sector regime is still profoundly regulated by administrative practices and planning is the predominately underlying institutional reason for the challenges described. From an economically theoretical perspective, a well-established electricity market could provide practical solutions to these challenge since the incentives could be more in line with the intended goals of deploying and using renewable energy.

An answer to the overarching research questions (*which mistakes occurred in Chin´s recent wind energy expansion development?*) is that the Chinese wind power case demonstrates how a market expansion with command-and-control innovation policies, does not necessarily lead to technological learning. A crucial lesson for policymakers is that fostering the technological capability of local industry can be cumbersome. Paraphrasing Kirzner´s (1985) observation; if one only looks at how many new plants are constructed and the generating capacity one might miss “light-bulb-moments” that could have made every wind plant more efficient.

Therefore, in order to mitigate the problems, China needs to adopt comprehensive strategies, which to some extent are suggested above. Strategies in the area of planning, policy and technical levels to improve the further development of the wind power sector is much needed. The results indicate that further quantitative analysis of renewable energy diffusion should be fruitful, and as such represent a complement to the vast number of qualitative case studies in the field. There are several ways to improve the analysis carried out here if more papers were to be examined and other problematic areas were to be added, this paper had a set limited scope, so some interesting and not less important issues have been left out due to a limited word count.

Outstanding questions include: are these findings of interest for countries like, for example, India which is beginning a push towards renewable energy? The short answer is that it is likely that there are a lot of energy policies learning opportunities from the Chinese case.

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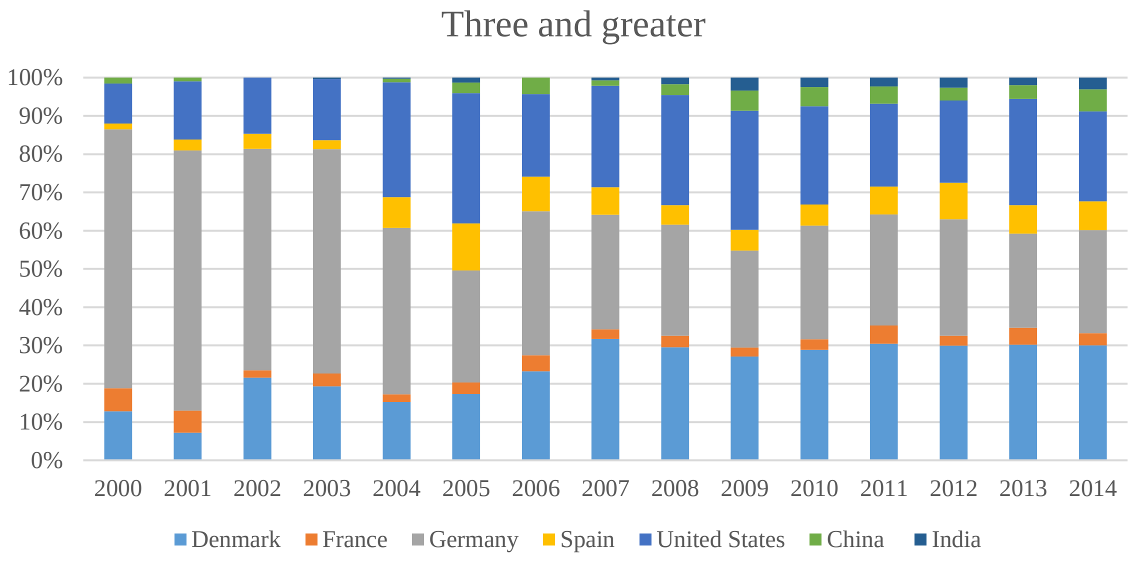
Appendix A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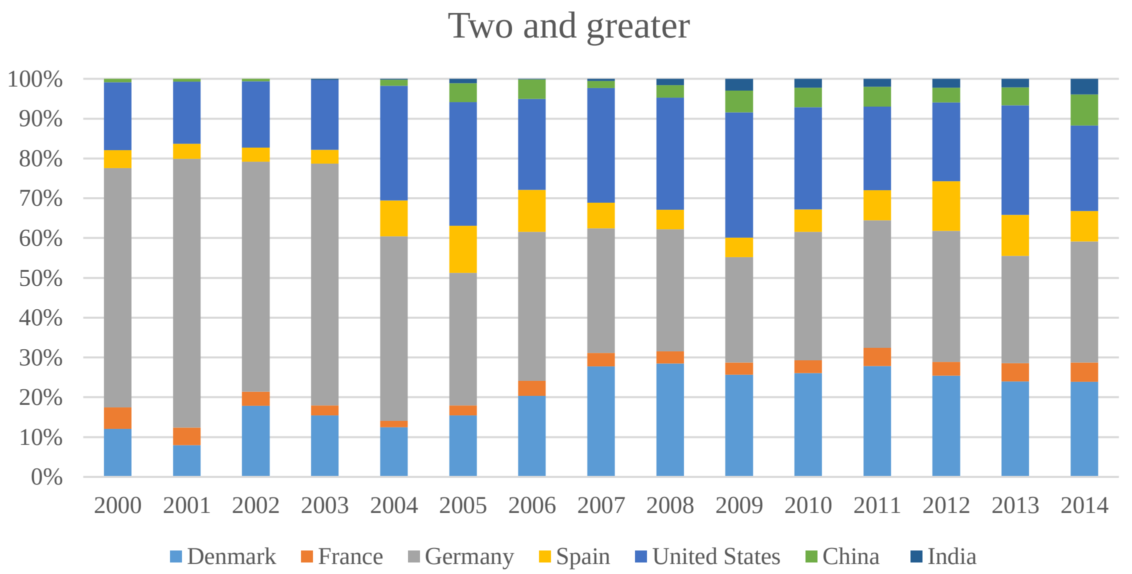
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