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Innovation paths in the Chinese wind power industry

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Joint project with:

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Preface

Mitigating climate change by reducing carbon emissions is one of the biggest and most complex issues the world has ever faced. Technological innovation plays a major role in taking on this challenge. Old and new industrial powers alike are increasingly reforming their policy frameworks to encourage low carbon innovation, and investments are following.

Evolutionary economics has clearly demonstrated how initial choices of technologies and institutional arrangements preclude certain options at later stages; hence, situations evolve in an incremental and cumulative way, resulting in context-specific technological pathways. Such path dependency implies that technologies and institutions do not progressively converge toward a unique best practice, as neoclassical equilibrium models might suggest. The historical and social embeddedness of such evolutionary processes instead results in a variety of very different technologies and institutions across countries.

The starting assumption of our research was that low carbon technologies depend on politically negotiated objectives and policies to a particularly high degree, mainly due to the failure of markets to reflect environmental costs. The way national governments and industries deal with the low carbon challenge varies greatly depending on levels of environmental ambition, technological preferences (such as different attitudes towards nuclear energy, shale gas, carbon capture & storage), the ways markets are regulated, and the importance attached to expected co-benefits (such as exploiting green jobs or energy security). Consequently, low carbon technologies are more likely to evolve along diverging pathways than other technologies whose development is more market-driven.

To test this assumption we conducted the international research project “Technological trajectories for low carbon innovation in China, Europe and India”. The project explored whether, to what extent and why technological pathways differ across countries. Case studies were conducted in two technological fields, electromobility and wind power technologies, in China, India and leading European countries. Whether a diversity of pathways emerges or a small number of designs becomes globally dominant has important implications. From an environmental perspective, diversity may help to mobilize a wide range of talents and resources and deliver more context-specific solutions. Convergence, on the other hand, might help to exploit economies of scale and thereby bring about bigger and faster reductions in the cost of new technologies. From an economic perspective, diversity may provide niches for many firms, whereas a globally dominant design is likely to favour concentration in a small number of global firms – which may or may not be the established ones. Comparing European incumbents with Asian newcomers is particularly interesting, because China and India might well become the gamechangers – responsible for most of the increase of CO_2 emissions but also leading investors in green technology. In addition, the project explored lessons for international technology cooperation, emphasizing ways to navigate the trade-offs between global objectives to mitigate climate change effects and national interests to enhance competitiveness and create green jobs locally.

The project was carried out between 2011 and 2014 as a joint endeavour of four institutions: the German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE), Institute of Development Studies (IDS) Brighton, Indian Institute of Technology (IIT) Delhi and the School of Public Policy at Tsinghua University, with additional collaborators from the Universities of Aalborg, London and Frankfurt. The project was truly collaborative, to the extent that international teams jointly conducted interviews in China, India and Europe which helped to build common understanding.

Eight reports have been published in, or are currently being finalised for, the DIE Discussion Paper series:

1. Schamp, Eike W. (2014): The formation of a new technological trajectory of electric propulsion in the French automobile industry.
2. Chaudhary, Ankur (2014): Electromobility in India. Attempts at leadership by businesses in a scant policy space.
3. Altenburg, Tilman (2014, forthcoming): From combustion engines to electric vehicles: Implications for technological trajectories. Case study Germany.
4. CHEN Ling, Doris FISCHER, SHEN Qunhong and YANG Wenhui (2014, forthcoming): Electric vehicles in China – Bridging political and market logics.
5. Lema, Rasmus, Johan Nordensvärd, Frauke Urban and Wilfried Lütkenhorst (2014, forthcoming): Innovation paths in wind power: Insights from Denmark and Germany.
6. DAI, Yixin, Yuan ZHOU, Di XIA, Mengyu DING and Lan XUE (2014, forthcoming): Innovation paths in the Chinese wind power industry.
7. Narain, Ankita, Ankur Chaudhary and Chetan Krishna (2014, forthcoming): The wind power industry in India.
8. Bhasin, Shikha (2014, forthcoming): Enhancing international technology cooperation for climate change mitigation. Lessons from an electromobility case study.

On the basis of these case studies, the team is currently working on a series of cross-country comparative analyses to be published in academic journals.

The research team is very grateful for generous funding and a very supportive attitude by the Swedish Riksbankens Jubileumsfond under a joint call with Volkswagen Foundation and Compagnia de San Paolo.

Bonn, April 2014 Tilman Altenburg

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1 Introduction

Climate change is becoming one of the most important issues facing human development. Countries, states, and cities are searching for solutions to reduce greenhouse gas emission by changing human development mode accordingly. The philosophy of “low-carbon development” is widely discussed and accepted as the future developmental mode of reducing carbon dioxide emission while preserving economic growth rate. Consensus is made that technological innovation and development may help human beings to fulfill the low-carbon development goal. Kyoto Protocol, for example, indicates that Annex I countries should “research on, and promotion, development and increased use of, new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies” in order to fulfill their responsibilities in reducing GHG emission. As the first agreement human being made in response to climate change, the Kyoto Protocol took developing countries (countries not in Annex I) mainly as technology receiver.

In practice, different countries encourage multiple technology developments. European Union took a leading position in response to climate change both in terms of equipment production and technology deployment. Technologies such as renewable energy, electronic mobility, power storage, fuel cells, energy efficiency technology, carbon dioxide capture and storage technology (CCS), and others are highly promoted in countries such as Denmark, Germany, France, and UK in their recent national strategy plans (BMWi & BMU, 2010[1]; Council for Science and Technology Policy, 2008[2]; 2009[3]; DEA, 2007[4]).

The world economic development and GHG emission distribution has changed since 1997. Emerging powers appear with high-speed economic development rates as well as increasing amount of GHG emission. China, India, Russia, Brazil became important players in the global climate strategy although they have not been included in the Kyoto Protocol.

Keeping the high economic development rate between 8-10% for almost a decade, China not only experienced fast economic and social development, but also paid heavy environmental cost. China overtook the U.S. and became the world largest emitter(IEA, 2007). The numbers of smog days with heavy air pollution in Beijing exceed 51% in 2013[1]. Facing international pressure over GHG emission reduction and severe domestic environmental situation, China showed great efforts in making climate change strategy and gearing the economic development direction to low-carbon mode. In the area of renewable energy, China occupied a large share of wind turbine market. The increasing share of market and high growth rate of the

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[1] Data source: Calculated from Beijing air quality monitoring station data, http://www.bjmemc.com.cn/g372.aspx

industry makes China a potential competitor with developed countries in the field of wind energy.

Particularly, China presents different technological innovation path. With relative slow R&D capacity, Chinese firms leapfrogged through importing production lines, gaining technological licenses through acquisition, and intellectual property purchase. The strong manufacture base, lower labor cost, and large amount of investment over the industry makes Chinese wind energy technology present a different path comparing with it EU counterparts.

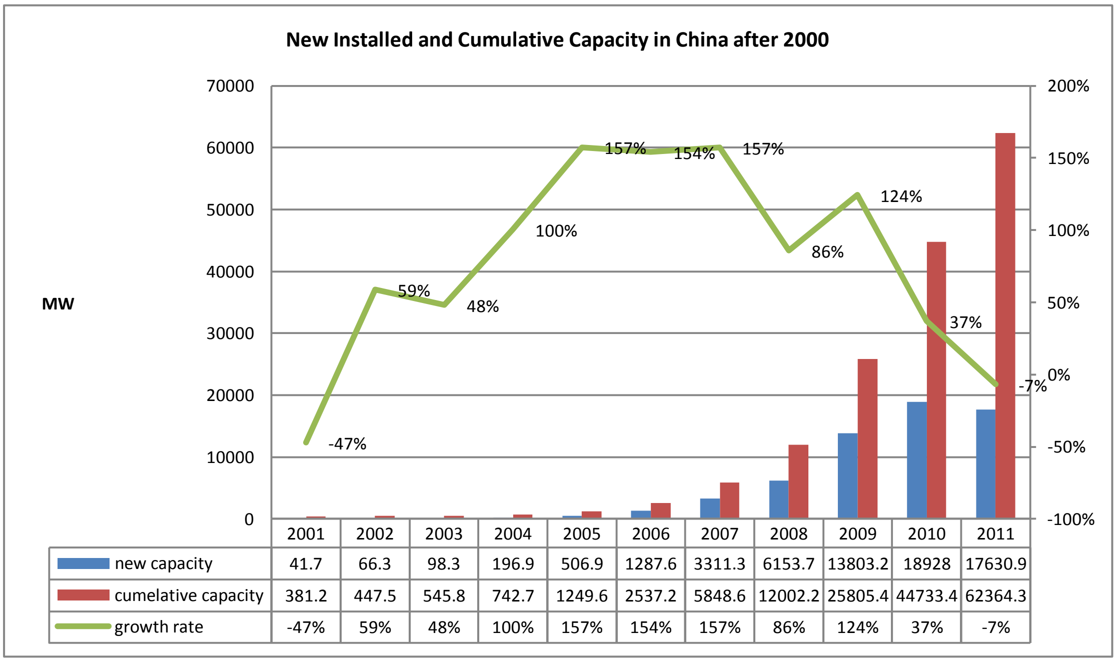
The important question is: "how and why do the emerging technological innovation path in Europe, China and India differ"? and "what are the implications for strategies of international competition and cooperation at the enterprise and government level"? As one of the country-focused research branch, this report focuses on China's technological innovation path, and decomposes the two big research questions into three sub research questions:

1) What is the technological innovation path in China in response to climate change?
2) How did the innovation path emerge? And why?
3) How did the innovation path influence the international competition and cooperation?

1.1 Key Research Questions

Last thirty years saw a dramatic development in Chinese wind industry. On the one hand, China gained core technology capacity for wind energy. Between 2004 and 2010, Chinese wind energy industry experienced an average annual growth rate of 130% despite the worldwide financial crisis (see Figure 1). In 2011, 29 major wind turbine manufacturers produce parts, equipment, and wind turbine systems in China. Having installed 17.63GW wind turbines in 2011, China became the global leader both in terms of annual installation capacity and the total installation capacity that reached 62.36 GW and accounted for 40% of the global installed capacity. On the other hand, the scale of deployment expanded at fast speed. In 2011, grid-connected wind energy reached 71.5 kWh, which was an equivalent to 1.5% of the total electricity output in China. According to the national plan, nine large-scale wind farm bases of 10GW installation capacity each would be built by 2020. The deployment speed grew so fast that national planning was adjusted several times to fit the development.

While believing that innovation stands firmly behind Chinese wind energy development, this research tries to provide political economic analysis to answer "what" question and "why" question: What is the nature of the innovation path taken in China (if it has a different innovation path comparing to other countries)? If so, what are the determinants of it innovation path?



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
new capacity	41.7	66.3	98.3	196.9	506.9	1287.6	3311.3	6153.7	13803.2	18928	17630.9
cumelative capacity	381.2	447.5	545.8	742.7	1249.6	2537.2	5848.6	12002.2	25805.4	44733.4	62364.3
growth rate	-47%	59%	48%	100%	157%	154%	157%	86%	124%	37%	-7%

Figure 1 Chinese Wind Energy Industry Installation Capacity Change (2001-2011)

Data source: Li et al. (2012).

1.2 Methodology

In order to illustrate the overall country-sector-technology story, this research used case studies to explain the specific country innovation path for China with following steps.

Firstly, we explored different cases to present innovation path and its changes. An innovation case is "any event that has made an impact or has a potential to make an impact on the climate change mitigation potential of the technology."[2] To reveal key cases, the research team interviewed key stakeholders involved in wind technology development in China, including the government officials, technological experts, enterprises (manufactures, and wind farms), to identify initial innovation cases that may influence the innovation path in the industry. Then, more interviews were conducted following the "snow ball" strategy to extend the potential pool of technological innovation.

Among all cases mentioned by interviewees, this research selected three key cases for further exploration with two selection criteria. On the one hand, this research defined innovation emphasizing the commercialization stage rather than R&D stage. Therefore, all cases selected are either reaching the commercialization stage or had been commercialized with market investment. On the other hand, due to the huge

[2] The definition is taken from the collaborative research project "Technological Trajectories for Climate Change Mitigation in China, Europe and India".

number of innovation events in the wind energy sector, this research only selected technology or organization innovation that represents an innovation path of an important alternative innovation path. Therefore, the research did not focus on single incremental technology improvements that were conducted by different players in the industry.

Considering the continuity of any innovation event, this research tried to set up a relatively clear boundary for each case by identifying the type of the innovation and players. Therefore, this research could illustrate the path of technological innovation in each case.

Besides description, this report addressed key influential factors in each innovation case especially focusing on policy factors, firm's competition strategy, and the international collaboration. Questions such as whether and how innovation capabilities arise? What direction did innovation path take? Were addressed. Interview questions were adjusted for each case, thus, different stakeholders and their interests and actions could be well recorded for further analysis.

The report is organized as following: session two serves as the overall introduction sector providing a broad review of the industrial development of wind energy worldwide and the fast growth of Chinese wind industry from two aspects: production and market changes. The trend of technology development path and deployment projects are described in session three. Session four provides three cases to illustrate the key influential factors of Chinese wind innovation path change. Conclusions and discussions are presented in session five with further research directions.

2 Wind Power Development in China

2.1 Context Background of Worldwide Wind Technology Development

Wind energy is an important renewable resource that experienced dramatic development since the late 1970s. Two reasons drove this development: the energy crisis in early 1970's boosted wind power as a global industry based on technology evolution. Global concerns over climate change, especially the execution of the Kyoto Protocol opened up world market for renewable energy. As the pressure of greenhouse gas (GHG) emission reduction kept increasing, the wind energy contributed larger share in world energy consumption. In 2008, the wind energy provided for nearly 20% of electricity consumption in Denmark, more than11% in Portugal and Spain, 9% in Ireland and nearly 7% in Germany, over 4% of all European Union (EU) electricity, and nearly 2% in the United States (IEA Wind, 2009). The total installed wind power capacity increased from 7,480 MW in 1997 to 237GW in 2011, representing a 31 times increase. All together, wind power provided 500 TWH per annum, which is an equivalent to 3 % of the global electricity consumption (IEA Wind, 2009).

Table 1 Top Ranking Countries for Wind Deployment (2011)

Installed Capacity per Capita (W/Cap)		Installed Capacity per Land Area (kW/sqkm)		Installed Capacity per GDP (kW/million USD)	
Guadeloupe	745.9	Guadeloupe	361.2	Cape Verde	20.6
Denmark	710.1	Aruba	168.5	Denmark	19.5
Bonaire	689.4	Denmark	91.1	Portugal	16.5
Spain	463.5	Germany	81.4	Spain	15.8
Ireland	434.9	The Netherlands	56	Aruba	12.5
Portugal	379.5	Portugal	44.3	Ireland	11.8
Germany	356.9	Spain	42.9	Germany	9.8
Falkland Islands	318.5	Bonaire	36.7	Falkland Islands	9.5
Sweden	307.9	Belgium	35.3	Dominica	9.4
Aruba	295.6	Ireland	28.9	Sweden	7.9
Canada	154.7	Curacao	27	Estonia	7.5
Greece	151.2	UK	24.7	China	6.3
USA	149.8	Italy	22.4	New Caledonia	6.1
New Zealand	145.2	Luxembourg	17	Cyprus	5.8
Estonia	143.4	Taiwan	15.7	Bulgaria	5.5
The Netherlands	138.2	Cyprus	14.5	New Zealand	5.2
Austria	131.9	Austria	12.9	Greece	5.1
Cyprus	119.6	Greece	12.3	Honduras	4.6

Norway	110.8	France	10.3	Curacao	4.2
		Dominica	9.6	Vanuatu	4.2

Source: Source: Calculation based on the data provided by The World Wind Energy Report 2011

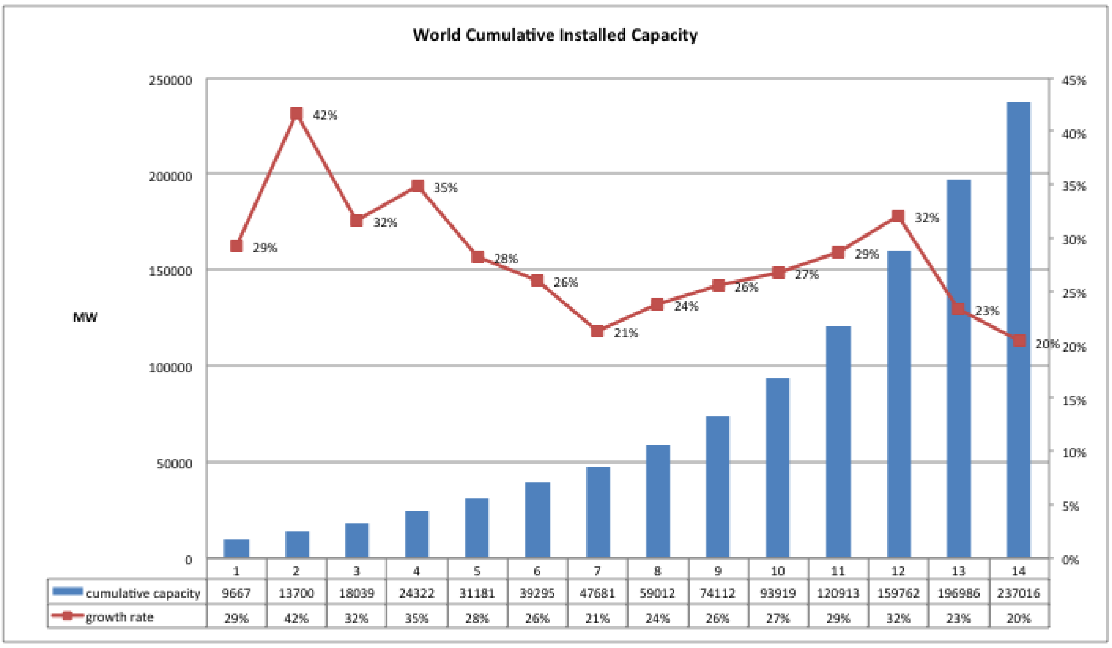


Figure 2: World Total Installed Capacity, 1997-2011 (MW)

Source: Calculation based on the data provided by The World Wind Energy Report 2011

The average growth rate is defined as the ratio of the new installed wind power capacity to the installed capacity of the previous year. Wind energy experienced a stable and high average growth rate of above 20% in past fifteen years. The turning point appeared in 2009 due to the global financial crisis. Yet, in 2011, accumulated new installation still reached the historical high of 40 GW (Gsanger, Pitteloud, 2012).

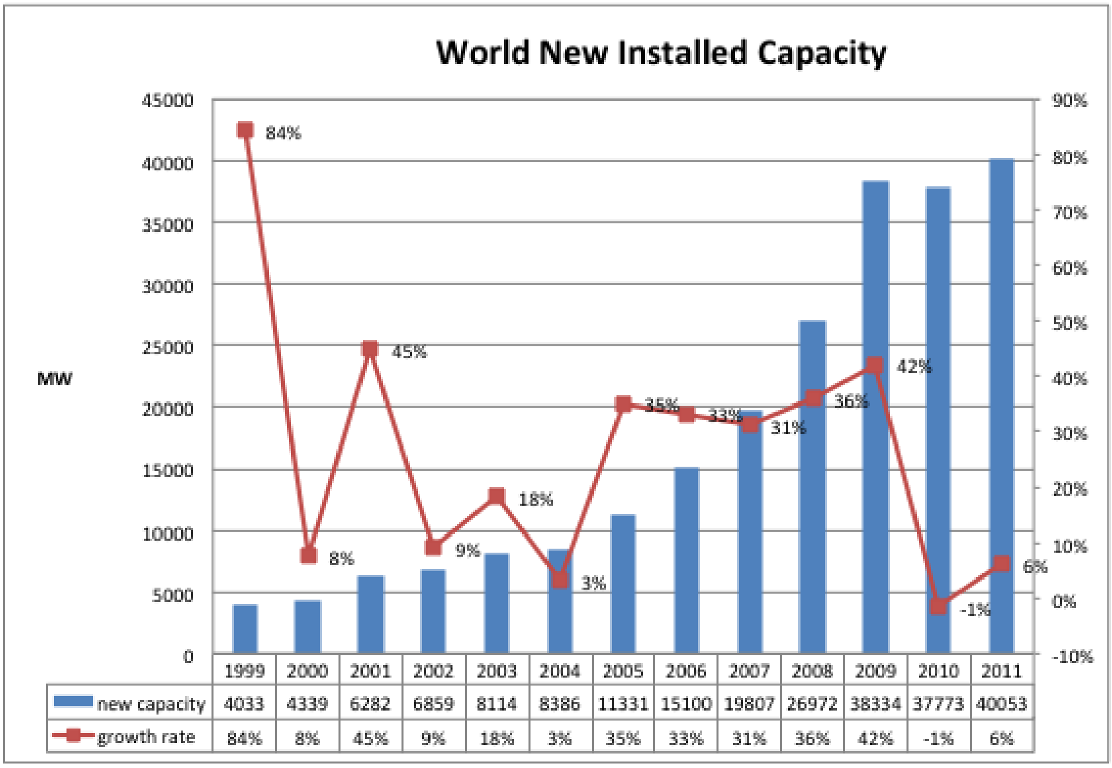


Figure 3 World New Installed Capacity, 1997-2011 (MW)

Source: Calculation based on the data provided by The World Wind Energy Report 2011

The distribution of the world wind energy market saw an obvious shift in production capacity and deployment scale during the past two decades. Initially, developed counties, such as Denmark, United States, United Kingdoms, and Germany, led the early attempts to develop wind power energy in response to climate change. Both the technology development and market development were dominated by these countries. Emerging economies such as China and India started to catch up around the end of the 20th century and rapidly gained large market share gradually. In 2011, both China and India were listed in the top five market owner in terms of the accumulated installation capacity. China, particularly, ranked the first (see Figure 3). The degree of market concentration kept increasing with top 10 countries occupying 87% of the world market. Meanwhile, the market distribution was hard to predict since the growth rate of emerging powers is dramatically higher than those "traditional giants" (see Figure 4).

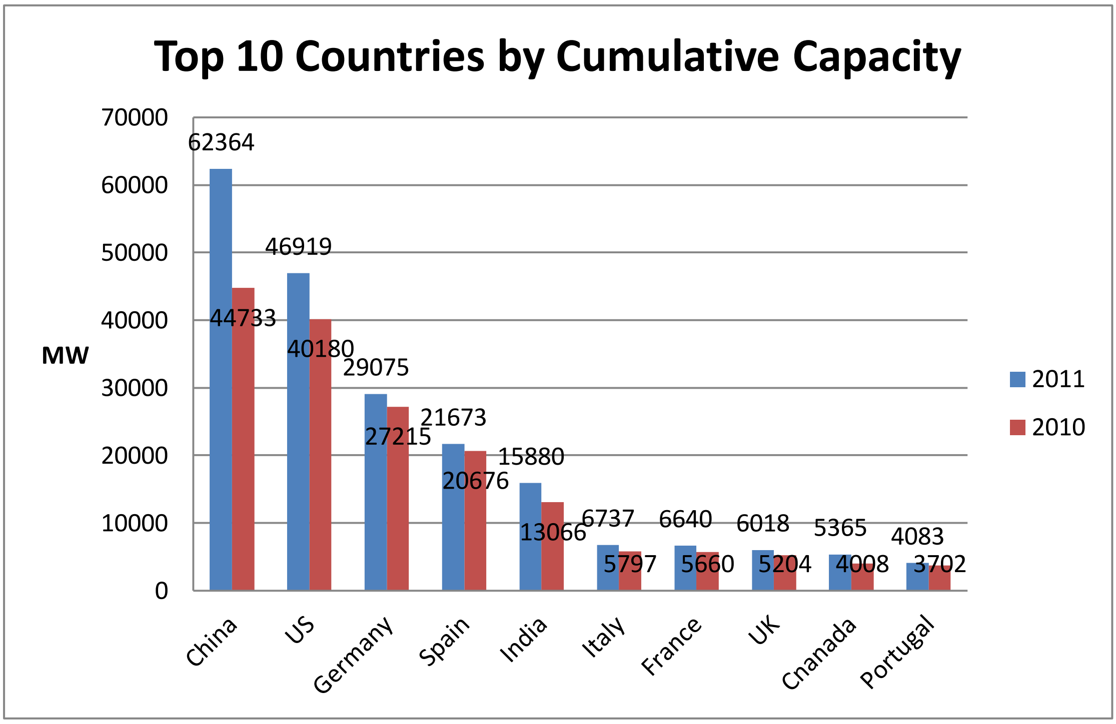


Figure 4 Top 10 countries by Cumulated Capacity

Source: Calculation based on the data provided by The World Wind Energy Report 2011

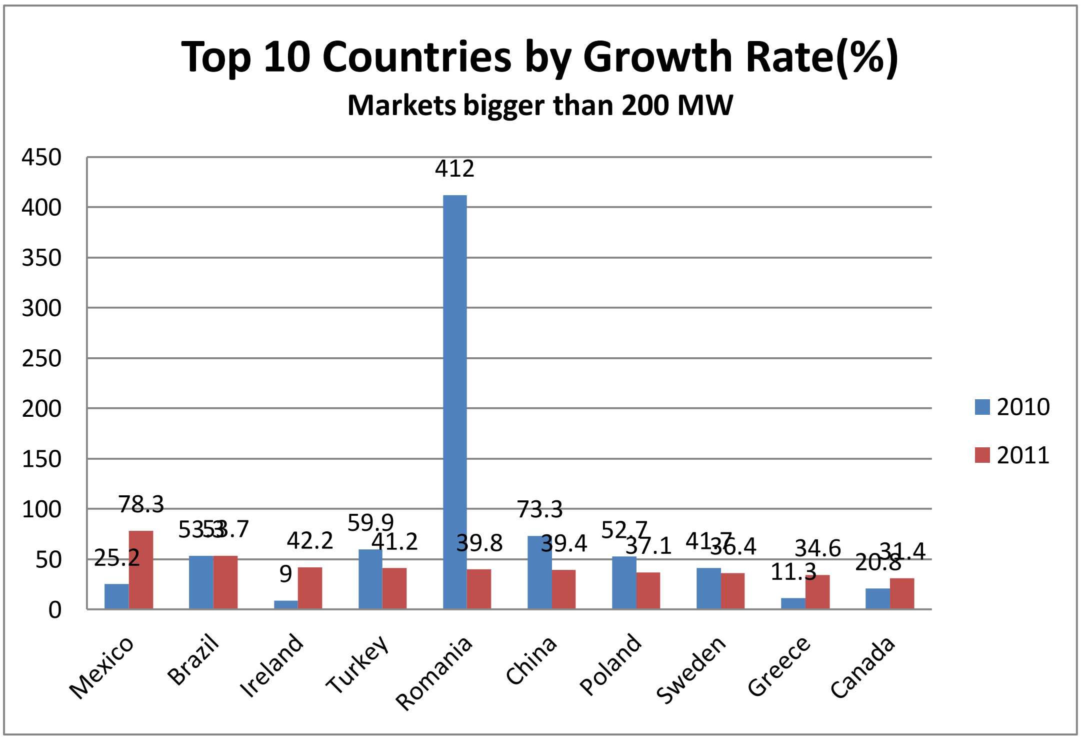


Figure 5 Top 10 countries by growth rate (%)

Source: Calculation based on the data provided by The World Wind Energy Report 2011

Besides manufacturing capacity, developing countries still needed to catch up with cumulative deployment. Indicators such as installed capacity per capita, installed capacity per land area, and installed capacity per GDP described the cumulative deployment level for different countries. The global average density of wind capacity per person is 34 Watt. Denmark's density had reached 7101 W/Cap in 2011, and Spain's, Ireland's, Portugal's, and Germany's were 4635 W/Cap, 4349W/Cap, 3795 W/Cap and 3569W/Cap respectively. China ranks 34th, with 46 W/Cap, India is on position 51 with 13W/Cap, below the global average. In installed capacity per land area, Denmark's and Germany's density had reached 91.1 kW/km^2 and 81.4 kW/km^2, on leading positions in large economies. In installed capacity per GDP, Denmark also maintained its leading position with 19.5 kW/ million USD. Portugal's and Spain's indicators reached 16.5 kW/ million USD and 15.8 kW/ million USD respectively (Gsanger, Pitteloud, 2011)

According to IEA, wind energy industry will continue to grow. It is estimated that the share of electricity generation from wind could reach 12% by 2050. Meanwhile, two major trends would be expected with the wind energy development towards 2050. On the one hand, more countries would join the competition and cut the market share. For example, by 2030, non-OECD economies will produce 17% of global wind energy, and this ratio will rise up to 57% in 2050. On the other hand, technology improvement would play significant role in wind development. As technology developed, wind generation costs would fall to 77% of current level, which might end around 70 to 130 US dollars per MWh. Technology development may also encourage offshore wind deployment. Concurrently, offshore wind farm cost as much as twice the onshore investment. Therefore, there were few offshore wind farm commercial projects although there were good quality offshore wind resources. With technology evolution, it is estimated that the offshore wind farm will have 38% of the cost reduced by 2050. The wind energy development also relied on other supportive factors, such as market mechanism building (i.e. carbon tax) or public policy (IEA, 2009).

2.2 Overview of Wind Energy Industry in China

2.2.1 Background of wind energy development in China

The energy demand of China kept increasing along with its fast economic development. The total energy consumption of the nation leaped from 987 million tons in 1990 to 3.54 billion tons of standard coal in 2010, making China the largest energy consumption country in the world (Wang, 2012). China started to become net oil importer in 1993, and net coal import in 2009 with t over 100 million tons coal imported per year (Wang, 2012). From 2006, the price of fossil fuel fluctuated severely in global markets. China confronted great pressure of energy reliance and energy security.

Historically, China relied on coal as its main energy format due to its mineral resource structure. The share of coal in total energy consumption reached 70.5% in 2010. Massive coal consumption made China big emitter of CO_2, SO_2, NO_x, and industrial dust. In 2009, Chinese government promised to reduce 40% to 50% CO_2 emission of 2005 level before 2020, and raised the share of non-fossil energy consumption up to 15% (Wang, 2012). China's non-fossil fuel energy production mainly came from hydro energy, nuclear energy, and wind energy, yet, they only accounted for 284 million tons standard coal, and equivalent of 8% of total energy consumption in 2011 (Wang, 2012). Environment protection pressure also pushed China to develop renewable energy consumption in fast speed.

Wind energy, unlike hydropower and nuclear power, encountered less argument in ecosystem protection, migrant's replacement, and radiation pollution, thus, was believed to be a safe renewable energy. The cost of wind energy also reduced to a level that made it competitive with coals in the electricity market, which is far below the level of photovoltaic energy and biomass energy. Moreover, scale effect of massive production and deployment of wind energy would further lower down the cost of wind farm construction and operation. Therefore, to develop wind energy is a rational choice for China to reach its energy plan of the 21st century.

2.2.2 The capacity and deployment boom in China

China has huge amount of wind resource within its territory[3]. It started to explore wind energy resources back in 1950's with the goal to provide rural energy supply. Wind-powered water lifting machine was one of the products developed in this period. Pilot study and trial deployment of wind energy for electricity generation purpose started in 1970's in response to energy crisis. However, the real industrialization never started till 1986 when China had first wind turbine operated for electrivcity generation.

After the execution of Kyoto Protocol in 2003, Chinese wind industry experienced a quick growth both in terms of manufacturing capacity and installed capacity along with the expansion of the international wind market (Li, 2007; Li et. al., 2009). Between 2004 and 2010, Chinese wind energy industry experienced an average annual growth rate of 130% despite the worldwide financial crisis (see Figure 2.1). Having installed 17.63GW wind turbines in 2011, China became the global leader both in terms of annual installation capacity and the total installation capacity that reached 62.36 GW and accounted for 40% of the global installed capacity (CWEA, 2012).

In 2011, grid-connected wind energy reached 71.5 kWh, which was an equivalent to

[3] This data varies in different reports and documents. This paper cites the latest data got in a recent interview with Center for Wind and Solar Energy Resources Assessment, China Meteorological Administration on July 17th, 2012.

1.5% of the total electricity output in China. The calculation reveled that 22 million tons of coal were saved from being burned, as well as 360,000 tons of sulfur dioxide and 70 million tons of carbon dioxide being hold from emission. Providing a household needs 1500 kWh every year, the grid-connected electricity in 2011 could suffice the electricity demand of 4700 households (Li et al., 2012). According to "Revitalization and Development Planning of New Energy Industry", China would not only continue developing onshore wind technology, but also targeting at the commercialization of off-shore wind technology in the near future.

China adopted large-scale wind deployment strategy nationwide. According to the Wind development national plan of 2007, seven large scale wind farm bases with 10GW installation capacity each would be built by 2020 (see Figure 6). The plan set up the target of installing 58.08 GW wind turbines by 2015, and 90.17 GW by 2020, and of taking account of 60% of the total installed capacity. In 2011, newly approved installation capacity in these wind farm base was 20.91 GW and was 14% more than 2010 target. Each wind farm base contained multiple wind farms.

Table 2 Planned Capacity of Main Wind Bases

Location	Planned Capacity (GW)
Xinjiang Kumul	10.8
Gansu Jiuquan	12.7
Hebei	14
Jilin	23
Jiangsu coast	3 GW onshore and 7 GW offshore
Eastern Inner Mongolia	20
Western Inner Mongolia	37

Source: China Wind Energy Outlook 2012

Comparing to the full swing onshore wind deployment, China's offshore wind farm was still in the infant development stage. By the end of 2011, national offshore installed capacity was 242.5 MW. Shanghai Donghai Bridge stage one project was the first large-scale commercial offshore wind farm in China, with designed capacity of 102 MW (Li et al. 2012).

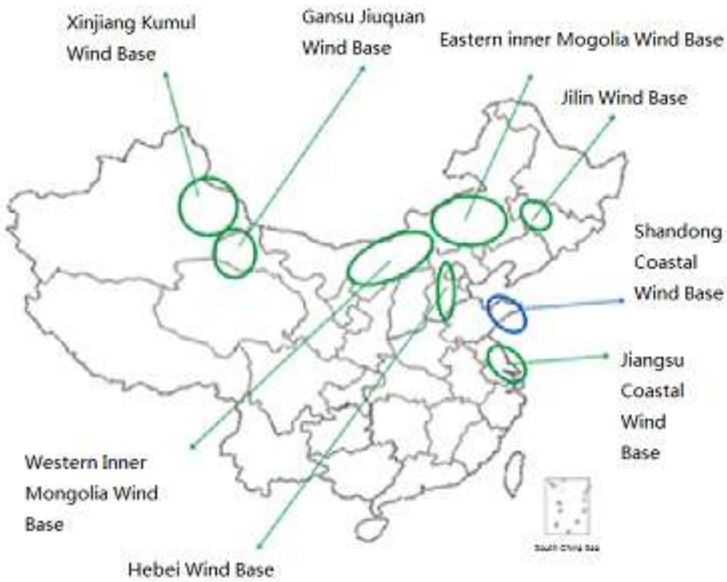


Figure 6: 10 GW Level Wind Bases Distribution in China

Source: 2013 Report on the Development of China's Strategic Emerging Industries, in China Institute of Engineering Development Strategy (2013)

Table 3: Provincial Cumulative Installed Capacity in 2011

Province	Cumulative Capacity (MW)	Province	Cumulative Capacity (MW)
Inner Mongolia	14384.4	Shanghai	269.4
Gansu	5551.6	Hainan	254.7
Hebei	4991.3	Anhui	247.5
Liaoning	4039.5	Shaanxi	245.5
Jilin	2936.3	Henan	154
Shandong	2718.6	Beijing	150
Heilongjiang	2626.5	Hunan	133.8
Jiangsu	1704.3	Jiangxi	133.5
Xinjiang	1659.8	Tianjin	125
Ningxia	1361.5	Hubei	115.4
Shanxi	1035	Guizhou	60.9
Guangdong	933	Guangxi	49.5
Fujian	873.7	Chongqing	46.8
Yunnan	684.8	Sichuang	16
Zhejiang	320.6	Qinghai	14
Total		47835.6	

Data source: Li et al. 2012

2.3 Innovation Path for Wind Equipment Manufacture in China

Wind energy development supports prosperity in wind energy equipment production. In 2011, more than 70 wind turbine manufacturers registered in China, yet only 29 of had real production. Compared with 43 providers in 2009 and 38 providers in 2010, the amount of provides showed a trend of reducing, reflecting the more severe competition in market and market concentration. Among providers of newly installed turbines, five biggest enterprises included Goldwind (3600 GW in capacity and 20.4%), Sinovel (2939 MW, 16.7%), United Power (2847 MW, 16.1%), Mingyang Wind Power (1177.5 MW, 6.7%), and Dongfang (946 MW, 5.4%) (Li et al. 2012).

Domestic star manufactures included United Power, Mingyang Wind Power, XEMC, and Shanghai Electric showed increasing competitiveness through increasing production capacity, or through advanced technology capacity. The year of 2011 not only saw a decreased installed capacity from Sinovel, Goldwind, Dongfang, Vestas, and Gomesa, but also saw the emerging of other firms. With its considerable growth rate of 73% in 2011, for example, United Power became the most outstanding enterprises in Chinese market. It launched its 1.5 MW wind turbine in 2008, and finished 768 MW in installed capacity in 2009, which made it the fourth biggest wind turbine providers in Chinese market. It maintained its status with 1643 MW in 2010, and leaped into the big three in 2011. Moreover, United Power made big progress in R&D for new products. It initially produced 3MW turbines in 2010, and quickly launched its 6MW turbine in November, 2011, only 6 months later than Sinovel. Another star enterprise is XEMC. It kept stable and strong growth after launched its first 1.65MW turbine in 2008. It entered top ten group with 451 MW newly installed capacity in 2011. Although having less newly installed capacity in 2011, Goldwind and Sinovel still kept their first and second biggest manufacture positions in Chinese market. Goldwind, Sinovel, United Power, and Mingyang Power ascended to top ten manufacturers in the world (Li, et al., 2012).

The innovation within Chinese wind energy market showed three major shifts. Firstly, the market gradually turned from “lower-price preference” towards “higher-quality preference”. International competitors had strongest feeling about this trend. While interviewing Vestas China, the director of government relationship admitted “Vestas offered higher price than domestic companies, which prevented some local project focused on short term installation goals from choosing Vestas products. Yet, Vestas emphasized high energy production and life-cycle efficiency, which is gradually became a concept among Chinese governments”. International competitors used to lose bidding projects over the lower price domestic wind energy equipments could offer. But the illustrious performance in operation and turbine reliability helped international manufactures keeping a considerable share in China. Vesta and Gamesa are the instances. Wind farm operators took turbine security and reliability of the control system as the highest priority. In this sense, domestic manufacturers were urged to invest more on core technology R&D to increase the quality to maintain the market share.

Secondly, the unit capacity of wind turbines had kept increasing and experienced step transition. 1.5MW and 2.5 MW turbines dominated the Chinese wind deployment market for now. Before 2005, wind turbines with various unit capacities of 250 kW, 600 kW, and 850 kW were installed in the Chinese wind market. Lacking of large-scale wind farm, different demonstration projects and small commercial wind farms selected different turbine units. Imported wind turbines over 1MW were introduced into the Chinese market during the first and second concession bidding between 2003 and 2004 and were widely adopted in wind farm projects with similar unit capacity. 1.5MW wind turbine became the dominant unit capacity in wind farms. This showed huge difference with world market, according to Vestas, where 1.2 MW wind turbine had been dominant wind turbine (Interview with Vestas). 2MW wind turbine soon jointed the market and became one of the most popular turbine that occupied a large share of the market. Till 2007, wind turbines over 1MW occupied about 51% of the annual installation and made the average capacity reached 1.05 MW. This number rose up to 1.47 MW in 2010 and 1.646MW in 2012 (Navigate Research, 2013). More recently, large wind turbine started to appear. 2.5MW, 3MW or even larger wind turbines gradually reached the commercialization stage and entered into the market. The 3 MW wind turbine were in the massive production stage and were installed in different wind farms successfully. Domestic manufactures had pilot machines for 5 MW and 6 MW wind turbine in 2011.

Thirdly, Chinese domestic manufactures gained international reputation and started their internationalization procedure in fast speed. According to Handelsblatt (2012), four Chinese wind turbine manufactures were listed as the world top 10 wind producers. Sinovel, founded in 2006, was ranked as the world second largest wind manufacturer, which captured 11.1% of the total market share[4].

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[4] Sinovel experienced a down time since 2012, it fell out of top 5 market share in 2013. Yet, it still ranked 7 in the world market in 2012.

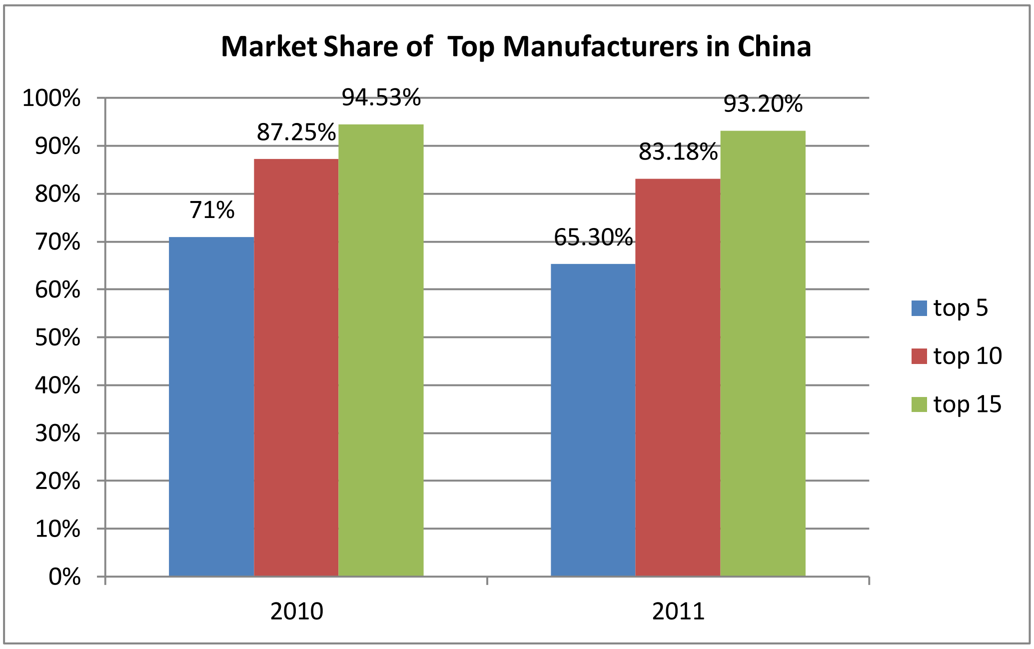

Figure 7: Market share of Top Manufactures in China

Source: China Wind Energy Outlook 2012

Table 4: New Installed Capacity and Cumulative Capacity of Top 15 Manufacturers in China (MW)

Enterprise	Annual Production (2010)	Cumulative Production (2010)	Annual Production (2011)	Cumulative Production (2011)
Goldwind	3735	9078.85	3600	12678.9
Sinovel	4386	10038	2939	12977
United Power	1643	2435	2847	5282
Guangdong Mingyang	1050	1945.5	1177.5	3123
Dongfang Electric	2623.5	5952	946	6898
XEMC	507	1089	712.5	1801.5
Shanghai Electric	597.85	1073.35	708.1	1781.5
Vestas	892.1	2903.6	661.9	3565.5
China Creative Wind Energy	486	682.5	625.5	1308
CSR Zhuzhou	334.95	465.3	451.2	916.5
General Wind Power	210	1167	408.5	1575.5
CSIC Haizhuang Windpower	383.15	479.25	396	875.3
Zhengjiang Windey	129	723	375	1098
Gomasa	595.55	2424.3	361.6	2785.9
Envision	250.5	400.5	348	748.5

Total	17823.6	40857.15	16557.8	57415.1

Source: China Wind Energy Outlook 2012

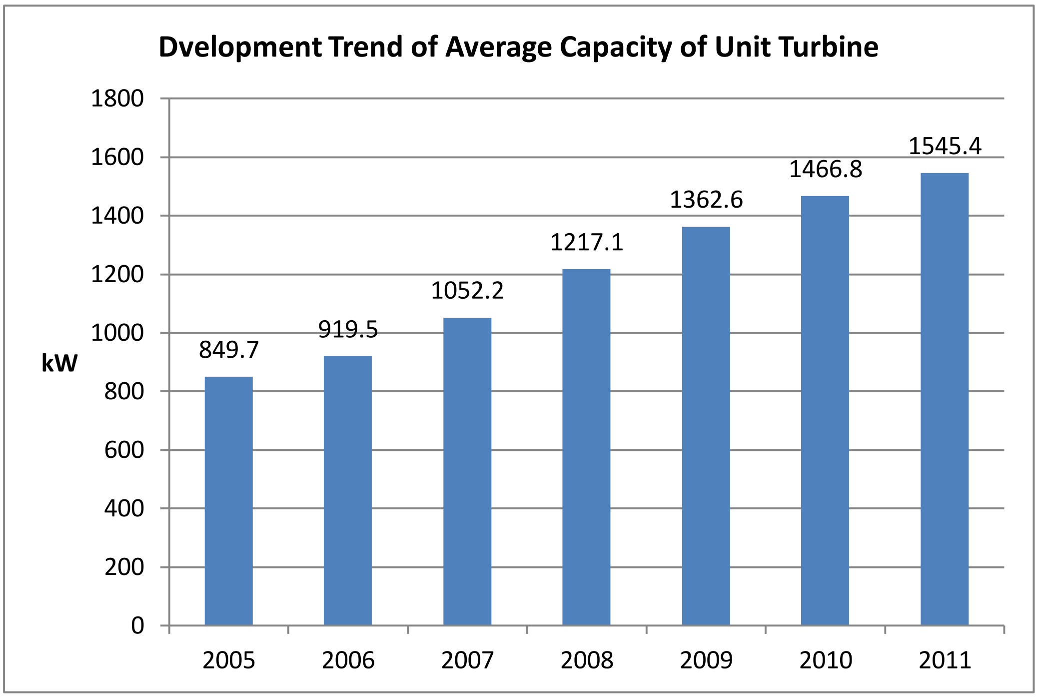

Figure 8: Development Trend of Average Capacity of Unit Turbine

Source: China Wind Energy Outlook 2012

2.4 Wind Deployment in China

In terms of wind energy technology deployment, China also experienced great shift in three dimensions.

2.4.1 Centralized deployment pattern shifts to combined pattern

First of all, the deployment pattern experienced "distributed demonstration stage", large-scale deployment strategy", to "diverse wind deployment strategy" stages.

Rich wind resource locates in Northern China, Northeastern China, and Northwestern China. However, these areas are sparsely populated, under developed in economy, and have less electricity demand. The industrialized areas, such as the southern and southeastern part of China, are far from wind rich areas. This explains why the initial wind demonstration projects mainly locate in Xin Jiang, He Bei, and Inner Mongolia. When China enlarged the development pace for wind energy technology in late 1990's, the cheap land cost and better wind resource condition made it easier for

China to adopt the large-scale, concentrated, mono-operator, and long-distance convey model of wind deployment to reach the economic efficiency goal. From 2008, based on national investigation of wind energy resource and wind resource distribution, China scheduled to build seven wind energy bases in Gansu, Xinjiang, Hebei, Western Inner Mongolia, Eastern Inner Mongolia, Jilin, Jiangsu and Heilongjiang respectively. By the end of 2011, seven bases started construction process, including Gansu Jiuquan 10 GW base stage I, Inner Mongolia Tongliao Kailu 10 GW Base, Bayanur Urat Middle Banner Base, Baotou Darhan-Muminggan Base, HebeiZhangbei Base stage I and II, Hebei Chengde Base, and Xinjiang Kumul Base. Another 6 wind bases had got construction approval and entered into early preparation stage.

However, large-scale deployment raised problems of grid-connecting and long-distance transmission. Since China was among the first adaptors of large-scale wind deployment in the world, it encountered many technological obstacles. For example, grid connection was a large one. Key technological questions included: how to improved the grid control system to eliminate the turbulence generated by the wind power? How to ensure efficiency in long-distance electricity transmission? Should ultra-high voltage (UHV) transmission line be built? Should the grid be upgraded to smart grid as a whole? Without providing suitable technical solutions to questions mentioned above, the electricity generated in large wind bases would encounter severe generation abundance. According to statistics of State Electricity Regulatory Commission (SERC), in first six month of 2010, Inner Mongolia had the most abandoned electricity, which equivalented to a share of 75.68% of total wind energy generated in the area (Li, et al., 2012).

While investing more on R&D with regarding to large-scale wind deployment, China also began to develop smaller-scale distributed wind farms in practice, especially in the southwest part of the country with two advantages: first, these areas had slower wind speed, but they are of the high population densities and with developed economies, therefore, electricity generated from wind farm is close to the end users, and could be accepted by the grid easily. Secondly, with progress in turbine technology, low speed wind turbine is close to commercial usage, therefore, there is no technique obstacles in developing distributed deployment model (NDRC, 2012).

2.4.2 Central owned firms dominate wind farm operation market

Secondly, wind farm operators gradually invade into the wind equipment manufacture. Worldwide, wind farm developers, operators, and wind equipment manufactures are different firms. They are specialized in different areas and formed the competitive market all together. Yet, in China, this situation is different. Electricity market, although under that process of marketing reform, is still monopolized by large state-owned enterprises, who naturally become main wind farm operators at the first place. Along with the investment rush after 2009 over wind farm construction, private investment gradually entered into the scene with small market share. At present more than 60 enterprises are either operating or constructing wind farm projects, most of which are central state-owned enterprises.

Chinese wind farm operators can be categorized into four groups: central state-owned enterprises, local state-owned enterprises, private or foreign enterprises, and wind manufacturers who extend their value chains to wind farm operation. Table 5 lists major wind farm operators under different categories.

Table 5 Four Types of Wind Farm Operators in China

Type of wind farm operators	Key Operators
Central state-owned enterprises	Guodian Longyuan, China Datang, China Huaneng, China Huadian, China Power Investment, Guangdong Nuclear Power, National Offshore Oil, CECEP, Shenhua (Guohua), Three Gorges Corporation, China Resources, State Grid, Sinohydro, HydroChina et al.
Local state-owned enterprises	Beijing Jingneng, Tianjin Jinneng, Shanghai Shennneg, Shandong Luneng, Guangdong Yudean, Ningxia Electric Power, Hebei Construction & Investment (Suntien Green Energy), Fujian Energy, and Fujian Investment & Development et al.
Private or foreign enterprises	Heilongjiang Zhongyu, China Wind Power, Golden Concord, Shanxi Yunguang Wind Power, Wuhan Kaidi, Daoda Marine Heavy Industry, HKC New Energy, Honiton Energy, UPC et al.
Wind manufactures	Goldwind, Gomesa, Zhejiang Huayi (HEAG), Tianwei Group, Shandong Changxing, Universal Wind Energy, and XEMC

Source: data collected through different reports from CWEA (2009. 2010. 2012)

Likewise Chinese wind manufacture market, wind farm market experienced dramatic changes as well. Basically, there are two trends. Firstly, it is more likely that central-government owned enterprises operate large-scale wind farms. In 2011, top ten wind farm operators installed capacity of 13.43 GW totally. Although this was 660 MW less than that in 2010, top ten enterprises occupied 1.8% more share of the total new installed capacity than the previous year. This centralization also occurred to top operators. For example, despite the average decrease in new installed capacity in 2011, Guodian Group, including Longyuan and Guodian Electric, got 370 MW more installed capacity than the previous year, keeping its position as the largest wind farm operator in the country. In this area, almost no private sector entered into competition to the high investment cost.

Secondly, the smaller-scale distributed wind farm market is emerging with no dominant enterprises. Many areas with less quality of wind resources are motivated to develop lower-speed wind farms. Like wind farms in Germany and Demark, many of these programs are of smaller-scale, with distributed features, and are closer to consumption. Therefore, future wind energy industry in China would have a chance of opening up more for private investments or for foreign enterprises.

Table 6: Top 10 Wind Farm Enterprises with largest new installed capacity in 2011

Explorer	Capacity (MW)	Market share (%)
Guodian Group	3860.5	21.9
Datang Group	2235.1	12.7
Huaneng Group	2229	12.6
Huadiang Group	1104	6.3
Guohua	1094.5	6.2
China Power Investment	866.3	4.9
China Resources	796.1	4.5
Guangdong Nuclear Power	527	3
Beijing Jingneng	372	2.1
Suntien	343.6	1.9
Others	4202.9	23.9
Total	17630.9	100

Data source: Li, et al. (2012)

Table 7: Top 10 Wind Farm Enterprises with largest cumulative installed capacity in 2011

Explorer	Capacity (MW)	Market share (%)
Guodian Group	12861.3	20.6
Huaneng Group	8578	13.8
Datang Group	8007.1	12.8
Huadiang Group	3829.9	6.1
Guohua	3440.1	5.5
China Power Investment	2944.9	4.7
Guangdong Nuclear Power	2891.5	4.6
China Resources	1773.4	2.8
Beijing Jingneng	1686.3	2.7
Suntien	1278.6	2.1
Others	15073.4	24.2
Total	62364.2	100

Data source: Li, et al. (2012)

Table 8: Top Wind Farm Enterprises with largest grid-connected capacity in 2011

Explorer	Capacity (MW)
Guodian Group	9812.9
Datang Group	6581
Huaneng Group	5743
Huadiang Group	2353
Guohua	2837.1
China Power Investment	2200.6
China Resources	2124
Guangdong Nuclear Power	1382.8
Beijing Jingneng	1340.3
Others	13460.4
Total	47835.6

Data source: Li, et al. (2012)

2.5 Policy Framework of Wind Energy innovation path in China

As an emerging industry, wind energy development depends on policy supporting in many dimensions. Existing literatures have indicated that both the manufacture and deployment pattern in Chinese wind energy industry are deeply influenced by its policy framework along the year (Li et al. 2009). Yet, studies focus more on explaining the causal effect between Chinese wind energy industry development and certain policy contexts. Therefore, it is common that existing literatures adopt the three analytical dimensions of demand, supply, and policy environment. This paper, however, focuses on the innovation path within the industry. Therefore, it emphasizes more on the changing trend of the technological innovation and the influential policy framework China provided along the way. Possible factors include: R&D investment, market development strategy, detailed policy supports in terms of environmental regulation, developmental planning, subsidy, or tax deduction

For each interviewee, we asked the question: "which Chinese policy play the biggest role in boosting wind energy industry development?". Many policies have been mentioned (see Table 9 for detailed policy context). Yet, Renewable Energy Law (REL) is of particular importance and was mentioned almost by all interviewees. Passed by the National People's Congress (NPC) in 2005, and revised in 2009, Renewable Energy Law was the milestone representing China's effort in promoting the development of renewable energy in the long run. REL clarifies the directions of renewable energy development as well as the rights and commitments of participants in legislative way. According to REL, all levels of Chinese governments are obliged to set technology benchmark and to issue necessary technology data for the market. Governments are also required to promote the connection of renewable energy electricity to the state grid. The law permits enterprises and governments to cooperate in terms of franchise, and enterprises have to carry out obligations in technology development and price controlling. Renewable energy electricity should be subsided so that it could be connected to the grid at the same price as traditional powers. The subsidy come from renewable energy funding collected in electricity utility bill from end users. Moreover, the law calls for further study on special funds and/or tax incentives for the development of renewable energy (NPC, 2006). Interviewees all indicated that REL is the policy that provide a long-term guarantee for the development of the industry, which greatly influenced all stakeholder's behavior.

Table 9 lists all other important policies about wind energy after 1994. A clear trend presented in the policy framework is the shift from industrial policy back to R&D policy and market policy.

Table 1 Policy combination in response to climate change in China (2001-2010)

Year	Innovation Policy	Industry Policy	Financial Policy	Environmental Policy	Energy Policy
2000	19%	6%	0%	61%	13%
2001	8%	0%	0%	84%	8%
2002	45%	3%	0%	42%	9%
2003	21%	0%	5%	51%	23%
2004	13%	0%	9%	52%	26%
2005	31%	12%	4%	35%	19%
2006	34%	0%	4%	42%	21%
2007	29%	2%	0%	41%	29%
2008	29%	6%	6%	3%	56%
2009	45%	8%	12%	8%	27%
2010	31%	10%	2%	16%	41%

First of all, energy policy and national strategy and planning set up the umbrella framework for all supportive policies. Starting from REL, a series of energy policy stimulating the development of renewable energy has been released by different ministries, including the Mid-Long term development planning for renewable energy (2007), the 11th five-year plan for renewable energy (2008), and revised version of REL in 2009. All these policies are not necessary particular policies for wind energy development. Yet, the national emphasis over renewable energy set up the big secene for wind development.

Particularly for wind energy, market exploration policy and or deployment policy served as the most popular policy tools Chinese government adopted. Starting from 2003, five rounds of recession projects were designed by NDRC with the target of enlarging domestic market. Higher market target were met by concession projects. As the supplementary support, regulations on grid connection, wind electricity price, as well as management of renewable energy fund all contributed to the development of the deployment and the industry to a great deal.

R&D policy presents special feature in Chinese wind energy development. Along with the national plan over science and technology development, research over wind energy had been included in the normal national research projects (i.e. 863 plan) ever since 1950's. There was no policy or research project specially designed for wind energy until recent. According to He Dexin, the President of Chinese Wind Energy Association, more policies are available for technology improvement and indigenous innovation. For example, the tax deduction policy for R&D fund, and special research fund support research over new type of wind turbine and design for wind blade. But he also pointed out that national support for wind energy research was still mainly conducted by universities and research institutes, the overall R&D could not be relevant until firms were motivated and join the R&D process as a key player.

Last but not the least, localization policy scattered in 1990's and early 2000's. Yet, it has been cancelled all in 2009, which marked that Chines market has been fully competitive. What we have to pay special attention is some policies once asked certain adoption rates of domestic equipment in wind farm construction. In 2009, the explicit items contravening free trade principles were all cancelled. However, Chinese government still attempt to support domestic manufacture and indigenous innovation through funding R&D or setting technology standards. Therefore, we keep the column of 'localization' in the table to mark the policies.

Table 9: Key Wind Energy Policies in China

Policy	Year	R&D	Manufacturing	Deployment	Localization	Remarks
The Regulation on Grid –connecting Operation in Wind Farm	1994			√		Regulatory measure
Regulations on Supporting Further Development of Wind Power	1999		√	√	√	Regulatory measure, Price supporting
The 10th Five-year plan for new and renewable energy	2001		√	√		Planning
Management Measure on Preparatory Work of Wind Power Concessions Projects	2003			√		Regulatory measure
Measures on Formulating Pre-report of Availability of Wind Farm	2003			√		Regulatory measure
Technological Regulation on Selection of Wind Farm Location	2003			√		Regulatory measure
Technological Regulation on Measurement and Assessment of Wind Resource	2003			√		Regulatory measure
Technological Regulation on Engineering Geological Detailed Investigation of Wind Farm	2003			√		Regulatory measure

Measures on Formulating Investment Estimation of Wind Farm Project	2003			√		Regulatory measure
National Technological Regulation on Assessment of Wind Resource	2004			√		Regulatory measure
Notification on Relevant Requirement Wind Power Construction Management	2005			√		Regulatory measure
Notification on Relevant Suggestion of Accelerating Localization of Wind Power Construction	2005	√	√		√	Planning & Subsidy
Interim Measures on Regulation of Land and Environment Protection Management in Wind Power Construction	2005			√		Regulation
Interim Measures on Special Fund Management for Development of Renewable Energy	2006	√				Subsidy
11th Five-year plan for renewable energy development	2008			√		Planning
Circular of the Ministry of Finance on the Adjustment of Import Tax Policies Governing the High Wind Power Generator Units and Their Key Parts and Raw Materials	2008	√	√			Tax rebating
Interim Measure of Management of Special Funds for Wind Power Industrialization	2008		√		√	Subsidy
NDRC Notification on Improving Price Policy of Grid-connected Wind Electricity	2009			√		Price supporting
NEB Interim Measure on Management of Offshore Wind Power Development	2010			√		Planning & Regulation
Views on Accelerating Smooth Development of Try to Wind Equipment Industry	2010	√	√		√	Planning

3 The path of wind energy innovation in China

3.1 Core Innovation Capacity Building in China

Chinese wind energy industry started to grow around 1980. The pathway through which China built up its innovation capacity can be divided into four stages (1) early R&D activities pushed by the government (1970s-1996); (2) imitative innovation based on imported product and technology (1997-2003); (3) cooperative innovation including collaborative design and joint venture (2004-2007); and (4)indigenous innovation based on internationalization and R&D globalization(2008-present)[5]. This innovation leapfrogging process happened along with the economic development of China in the past 30 years.

3.1.1 First stage of innovation capacity building – wind farm operation and domestic R&D based innovation (1970s-1996)

Government started to support wind technology development and deployment through setting up public R&D activities and operating wind farms with foreign donated wind turbines.

From deployment perspectives, most of wind energy equipments were applied at rural areas without connecting to the electricity grid in early 1970's. Therefore, there were no "real" wind energy deployments back at that time. As the domestic R&D on wind energy and scattered pilot wind turbines were set mainly for further research purpose. Commercial deployment didn't appear until foreign governments started to donate wind turbines to China for market exploration and built wind farms in various place in late 1980's. Xinjiang Wind Energy Company, the predecessor of Goldwind, was formed as an independent firm to operate Dabancheng Wind farm that had 13,150kW turbines from Bonus through the Denmark governmental loan. When the wind farm connected to the grid in 1989, it became the largest wind farm project in Asia. Other wind farms were built in provinces such as Shandong, Zhejiang, and were connected to the grid for the first time in 1988. This milestone not only showed an innovation path change in the sense that China had large wind turbines over 100kW for the first time, but it was also presented a deployment innovation path change: given the fact that China had its commercial wind farm for the first time, the operation process served as a training program for technicians and wind farm experts who became the backbone for Chinese wind R&D afterwards.

From technology development perspectives, the innovation capacity needs to be updated when the size of the wind turbine was greatly enlarged. China had the domestic 55 kW wind turbine under R&D when it purchased 150 kW and 250 kW

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[5] Ru P, Zhi Q, Zhang F, et al. Behind the development of technology: The transition of innovation modes in China's wind turbine manufacturing industry[J]. Energy Policy, 2012, 43: 58-69.

wind turbines through foreign governmental loans. Foreign purchase provided the opportunity for Chinese engineers and researchers to access to advanced wind technologies from other countries. Reverse innovation was also a method for Chinese researchers to access to advanced technologies. This innovation led to several key technological trajectories. For example, from 1992 to 1995, Xinjiang Wind Power Plant produced the key components of the 300 kW wind turbine based on knowledge gained through reverse innovation. In the mid-1990s, the first batch of 100 kW wind turbines in China was successfully produced through the coalition between the Zhejiang Institute of Mechanical and Electrical Engineering and the Hangzhou Power Equipment Plant, which was a reverse design from the 120 kW turbines imported from the Danish firm Bonus.

In its early stage, Chinese wind companies started to gain basic knowledge about wind energy. Yet, with relatively low research foundation about the technology, Chinese firms also clearly realized the technological gap between them and their international counterparts. Although the first few commercial wind farms were built with foreign wind turbines, the high cost of imported wind turbines prevented China from enlarging the deployment scale. Therefore, to lower the cost of wind turbines through localization became the main target for the following period.

3.1.2 Second stage of innovation capacity building – Imitation innovation based on imported technology import (1997-2003)

Starting from 1995, the central government published its first national energy planning that mentioned wind energy development: "Outline of New and Renewable Energy Development (1996–2010)". In the policy document, it was clearly addressed that the next target for Chinese wind energy industry was to import advanced technologies and equipment in order to absorb the technology and to develop domestic wind energy industry through localization. This key innovation pattern required a good connection between technology licensing and domestic R&D. The most successful practitioner of licensing was the Goldwind. Based on the license agreement of 600 kW turbines from Jacobs, and 750 kW turbines from REpower, Goldwind quickly grasped key technology and know-hows to enhance its technology capability, and successfully produced 600 kW and 750 kW turbines using local design and local parts in 1999 and 2001 respectively. Like in other industries, the process of "importing technology, digestion, and absorption" became an ideal model to gain technology improvement for wind industry (Dai and Xue, 2014).

3.1.3 Third stage of innovation capacity building – Cooperative innovation based on collaborative design and joint venture (2004–2007)

Wind energy market started to grow from late 1990's. By 2003, the cumulative installed capacity of China's wind power had shot up to 568 MW. The rapid market growth generated larger demand, however, with foreign wind turbine systems occupying 84.7% of the cumulative market share, the shortcomings of technology licensing reliance quickly showed up: it became expensive and hard to obtain cutting edge technology licensing. In turn, market enlargement was limited.

Firms started to change their strategies to gain core technological innovation capacity. They either had collaborative research projects or founded joint ventures with foreign firms with clear target to improve their research capacity. Many wind turbine manufactures established joint venture projects to carry out collaborative research. For example, Goldwind and the German firm Vensys started their collaborative project on 1.2 MW turbines in 2004. Besides, Garrad Hassan collaborated with Zhejiang Windey and Baoding Tianwei, Aerodyn collaborated with Shanghai Electric, CSIC Haizhuang, United Power, and Guangdong Mingyang. Yet, leading technology companies in wind energy, including Vestas and GE, preferred not to set up joint ventures with Chinese firms but to build branch factories in China as sole cooperation to keep their intellectual property right protected. Meanwhile, the cost of wind turbine decreased quickly.

The change of innovation path focused more on core technology development in this wave. Domestic firms benefited from collaborative research and released new wind turbines of their own design soon. Goldwind released its 1.2MW and 1.5MW direct drive wind turbine in 2005 and 2006 respectively[6].

3.1.4 Forth stage of innovation capacity building – Indigenous innovation based on enterprise internationalization and R&D globalization (2008–present)

The fourth wave of innovation path emerged along with the explosive growth of the wind turbine market expansion in 2008 through indigenous innovation activities. China successfully increased market share of domestic parts through localization policy and joint venture strategy. Till 2008, domestic wind turbines occupied 75.6% of the local market share, and leading domestic players gradually had the capacity to conduct indigenous R&D in each stage of the wind turbine lifecycle.

From deployment point of view, China became top players who had the largest cumulated wind energy installation capacity; from core technology development point of view, China had the capacity of producing cutting edge wind turbines. What is missing in the puzzle was the innovation capacity to guide future technology development. "When you are a follower, you know where to go because you may simply following the leader. The situation would be totally different when you become the leader in the industry. Firms like Goldwind and Huawei[7] need to decide what would be the next technology milestone and prepare for it through basic R&D in

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[6] Website of Goldwind, http://www.goldwind.cn/web/about.do?action=story, retrieved on 2013-5-5

[7] Huawei is a leading global ICT solution provider based in Shen Zhen, China. Started from 1987, Huawei had followed Cisco on router technology for 17 years and finally took the leading position.

the long run"[8]. Concurrently, key technological challenges for Chinese wind energy technology include: design and manufacture capacity for large wind turbines (i.e. 5MW or 10MW turbines for offshore wind farm installation), technical solution for wind energy grid connection (i.e. upgrade the grid control system to counteract the intermittence), technological solution for long-distance electricity transmission (i.e. extra-high voltage direct current supply), and efficient electricity storage solutions, etc. Both Chinese government and firms geared towards internationalization to stimulate potential technology trajectories.

Mergers and acquisitions (M&A), especially to foreign R&D sectors or wind design companies were key methods for domestic firms to have a shortcut to gain core technologies and foreign markets share, and to speed up their indigenous innovation capacity building . For example, Goldwind acquired 70% share of Vensys, its former partner in collaborative design, in 2008. In doing so, Goldwind started to establish its global R&D network consisting of three research centers, in Beijing, Xinjiang, and Germany. It became a wind leading company with strong indigenous R&D and design ability, independent intellectual property rights. All these not only brought 140 million dollar foreign sales in 2009, but also provide Goldwind long-term competitiveness, which helped it regain the first place in domestic market in 2013.

3.2 Wind Energy Deployment Technology Innovation Path in China

The technology innovation path for deployment is not as clear as core technology since the commercial deployment didn't happen until 2003 with strong government push. The deployment technology innovation is still under exploration both by the industry and by different level of governments. Therefore, this session mainly introduces the concurrent deployment pattern and the undergoing changes. It also mentions the way deployment innovation may influence core technology development.

3.2.1 Large-scale deployment pattern

Limited by the wind resource distribution, Chinese government decided to adopt large-scale deployment strategy to develop its domestic wind energy market. In 2008, National Energy Administration of NDRC highlighted wind energy as a priority area to develop. The bureau selected seven locations with rich wind resources and set up wind energy development target for each of them. According to the national wind power development plan, Hami(10.8 GW), Jiuquan(12.7 GW), Hebei(14 GW), Jilin(23 GW), Jiangsu coast(3 GW onshore and 7 GW offshore), Inner Mongolia East(20 GW) and Inner Mongolia West(37 GW) would be built by 2020. This top-down policy decision pattern influenced the deployment pattern in China for about ten years.

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8 Interviewing Zhao Yuwen on August 15th, 2013.

Another key feature to describe Chinese wind deployment strategy is “fast development”. The national target of wind development had been updated frequently with higher goals to reach in near future. In the 11^{th} five-years plan (2005), China targeted at having 10GW wind installation by 201. This goal had been replaced by the “National Mid and Long-Term Development Plan for Renewable Energy“ of 2007, which raised the target to 5GW wind installation in 2010, and 30 GW installation by 2020. This goal again had been replaced by the “Renewable energy industry revitalization and development planning” of 2008, which set up the target of having 35GW installation by 2011 and 150 GW by 2020. The speed of planned wind development is faster than most of countries in the world. This also changed Chinese wind innovation path dramatically.

As mentioned above, this large-scale deployment pattern encountered technical difficulties in recent years. A combination of large-scale deployment and distributed deployment is encouraged in the 12^{th} five-year planning for wind energy development. Low speed wind turbine technology is encouraged especially in provinces such as Guangxi, Zhejiang, and Yunnan where the wind resource is not supreme but could be easily transmitted to end users.

3.2.2 Deployment Technology innovation influenced core technology innovation

Deployment pattern can down force the core technology development through market pull effect.

Chinese wind deployment technology was dominated by few models, mainly of 1.5 MW and 2.5 MW. There were two reasons in the deployment process led to this technology path. First of all, when design and construct a large-scale wind farm, it is more important to investigate location. With large piece of flat land in the northwest part of China and its rich wind resources, data on wind resource distribution didn’t show huge difference within the area. thus, the same type of wind turbine could be adopted without lose the efficiency (Interview with Zhu Rong, China Meteorological Administration). Therefore, it would be easier for wind farm developers to select the most popular wind turbines within their budget. The large-scale deployment strategy was pursued starting from 2004 when 1.5 MW wind turbine started to dominate international and domestic market. Likewise, 2.5 MW wind turbines dominated wind farm construction projects when domestic manufactures were capable of providing cheap turbines through reverse innovation or joint R&D.

Secondly, with the fast speed of wind farm development in the nation, it left little room for farm developers to slow down the construction process waiting for better turbine technology to appear. This partially explained why larger wind turbines, such as 3MW, were rarely adopted in wind bases over 10GW.

The unit size of wind turbines has been increasing in recent years. Before 2005, wind turbines with unit capacities of 250 kW, 600 kW, and 850 kW dominated the Chinese market. Imported wind turbines over 1 MW were introduced into the Chinese market during the first and second concession bidding, it was adopted quickly: about 51% of the annual newly installed market was held by wind turbines over 1MW in 2007. The average rated capacity of wind turbine reached 1.0489 MW, and this number increased to 1.4668 MW in 2010 when large wind turbine became the mainstream product. Figure 9 shows the growth of wind turbine unit capacity from 2000 to 2010. More recently, multi-MW wind turbine production and application in China has made considerable progress. The 3-MW wind turbine has been put into batch production and installed successfully; furthermore, a prototype 5-MW wind turbine has been produced.

figure 5. Average rated capacity of newly installed wind turbines in China, 2000–2010.

Figure 9 Average rated capacity of newly installed wind turbines in China, 2000-2010

Source:

3.3 New technology and new deployment trend in China

In response to demand for flexible and efficient grid integration of large-scale wind power, considerable efforts will be made to develop and deploy grid-friendly technologies, including wind turbine technology, long-distance transmission technology and large-capacity storage technology, along with power system technologies.[9]

3.3.1 Wind turbines technology

Before 2020, wind turbine technical specifications, network testing and model certification will be used to develop grid-friendly wind turbines and wind farms that are more suitable to power networks with capabilities of active and reactive power

[9] China wind energy development roadmap 2050, working paper by Energy Research Insitute, NDRC, PRC and International Energy Agency.

rate control, reactive power adjustment, low-voltage ride through (LVRT), frequency control and anti-jamming. Before 2030, control systems, storage devices and auxiliary equipment will be developed and deployed so that wind farms can be controlled and adjusted like conventional power systems. By 2030, when large-scale energy storage technology is widespread, wind farms are expected to match the performance of conventional electricity generation, supplying electricity through distributed systems to end-users or working with other power generation technologies to become a hybrid power supply source.

3.3.2 Integration and long-distance transmission

Alongside improvements in power grid infrastructure and operation techniques, and traditional AC transmission for large-scale wind farms and long distances, more flexible DC, high-voltage DC (HVDC), superconductive and low frequency transmission technologies will need to be improved, especially for offshore wind farm electricity. Before 2020, while the super-high-voltage grid infrastructure has not been established, advanced technologies including dynamic reactive power compensation, series compensation/TCSC, controllable high resistance, and automatic voltage control (AVC) will be applied to improve wind power output and energy quality, as well as enhancing safe operation of the power system. For small capacity and near offshore wind farms, AC transmission will be used, but as capacity increases and far offshore wind farms are installed, flexible HVDC technology will be developed at a faster pace. After 2020, as effective solutions are found to HVDC power transmission constraints, efficiency and economic advantages will be maximised, enabling high-voltage transmission to provide effective protection to the development of large-scale wind power programmes. After 2030, superconducting technology will be used for grid access and long-distance transmission in China’s wind power industry.

3.3.3 Dispatching techniques

Dispatching control, a key part of power system construction, will play an important role in optimal allocation of power resources. The volatility of wind power and large-scale development of renewable energy technologies will increase the need for smart dispatching techniques. Wind turbine operational statistics and data analysis should be strengthened in order to gain accurate knowledge of wind power operational characteristics. Scheduling techniques and strategies should be studied to continuously improve more refined wind power scheduling. Smart grid technology will be integrated in dispatching control.

Before 2020, an integrated wind turbine/wind farm data collection and dispatching control system will be established to centralize forecasting, control and automatic wind power dispatching. By 2030, with initial smart grid construction, the integration of distributed co-ordination and control technologies will be developed, with control scope extended to the whole power system and intelligent wind power dispatching.

Operational control of large-scale variable power sources and of the overall system will be improved. Wind power and other renewable energy generation will be flexibly connected, transmitted and used.

4 Description of specific innovation cases

This research adopted two criteria for case selection. First of all, in order to describe the innovation path event, the case has to be a detailed event that reflects one type of the technology trajectories leading to technology path change in China. Secondly, the case has to contain enough information to show key influential factors that made this trajectory happen. We also hope that the causal relationship between the influential factors and technology trajectories being represented in selected cases.

4.1 GoldWind 1.2 MW Turbine Technology Development

4.1.1 Background information

Goldwind was founded in 1998 and headquartered in Xinjiang. As one of the earliest wind energy cooperation in China, it evolved in many wind energy businesses, including wind turbine design and manufacturing, wind resource assessment, and wind farm operation. According to data of 2011 and 2012, Goldwind was the largest manufacturer of wind turbines in China and the second largest globally. With strong, internationalized R&D capabilities, Goldwind has become the world’s largest manufacturer of Permanent Magnet Direct Drive (PMDD) wind turbines. For now, Goldwind had its branches and factories located in six continents.

Goldwind experienced several key technology innovation events along its development. This case describes the process of how Goldwind obtained its technology capacity and illustrates Goldwind’s innovation direction changes along the history as well as to the future.

Goldwind experienced a long process to accumulate its innovation capacity. The process contained three important stages. First stage was dated back to 1980’s when Goldwind started the development and marketing of 600kW and 750kW that led Chinese wind market. With little base of innovation capacity, Goldwind then established the joint research mechanism with Vensys on 1.5MW and 2.5MW direct drive wind turbines, which occupied around 20% of the total production capacity in 2012. These wind turbine models will dominate the major wind market in China for the next 3 to 5 years (Maximilian Hinz, 2012 interview). In this stage, Goldwind started its international collaboration strategy that left significant influence to its development later. In stage three, after executing its internationalization strategy, Goldwind is developing in-house innovation capacity on key products for the future, including wind turbines in 6.0MW and 10MW for offshore usage.

4.1.2 The technological innovation event on 1.2 MW wind turbine

Among these changes, the first joint research on 1.2 MW is of the most importance, which provides an example of how China is obtaining advanced wind power technology through internationalized research collaboration.

Goldwind started to learn from foreign technologies long before its joint research on 1.2MW turbine. In 1997, Xinjiang New Wind Company, the predecessor of Goldwind, licensed the 600 kW wind turbines from Jacobs to obtain the capacity of building largest wind turbines in China. Soon after, Goldwind obtained a license from REpower for its 750 kW turbine. In both cases, Goldwind insisted to include technician and researcher training in the contract. While Chinese engineers were sent to Germany for operational training, experts from Jacobs and Repower also went to China to provide on-site training. Through mutual communication and hand-by-hand teaching process, Goldwind improved its technology capability greatly and successfully produced turbines of 600 kW and 750 kW in 1999 and 2001 respectively. These experience formed the foundation for collaborative research in 2004. Wu Gang, CEO of Goldwind, realized that Goldwind did not have enough R&D capacity for independent innovation by the time, and promoted a “dumb-bell” business model for the firm. On the one hand, the firm developed its design and assembling capacity to catch the market need; on the other hand, market investigation and service should be the core competitiveness.

In 2003, Goldwind embarked on the collaborative design of 1.2MW magneto electric direct-drive wind turbines with Vensys. Unlike REpower, Vensys was not a manufacturing firm but rather a design firm who was looking for a partner with the manufacturing capability to realize the turbine design. The collaboration with Goldwind, however, was a hard decision. Goldwind produced doubly fed induction generator of 600kW and 750kW before, but Vensys only designed gearless turbine technology (direct drive gearless wind turbine), which was the minority both in the technology and market perspective. Goldwind had to consider many factors before choosing this new technology as a key innovation path. Advantages included that gearless turbine had less weight, less cost, less parts for maintenance and replacement. Goldwind finally determined to take the challenge. In 2005, Goldwind had the prototype of the 1.2 MW turbines and installed it in Da Ban City wind farm for pilot operation. That became the first wind turbine produced in China over 1 MW.

Goldwind learned a lot from the collaboration and improved the magneto electric direct-drive technology to produce 1.5MW（2007）, 2.5MW(2009) and 3.0 MW(2009) turbines independently. Goldwind had already commercialized the products of the 2.5 MW and 3.0 MW turbines. In summarizing key factors for the success of Goldwind, Wu Gang emphasized that “insisting on collaborative research, rather than licensing technology or purchasing turbine design solutions made Goldwind strong at independent technology development” (media interview, 2010)[10]

Goldwind continued its internalization process by purchasing Vensys in 2008. Owning 70% of it, Goldwind gained control over the direction of future research and

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[10] http://blog.sihna.com.cn/wpsp89600

development and convenient access to its intellectual properties. Wu Gang believed that it was important to give Vensys enough freedom on design and technology transfer to keep the top-design capacity of it. At the same time, Goldwind invested in Vensys to build new manufacture firm in Europe to compete in foreign market. This was also very helpful for Vensys to improve the quality of their designs through learning-by-doing. Now Goldwind has established a global R&D network consisting of three research centers, in Beijing, Xinjiang, and Germany, and has strong indigenous design ability and a large amount of patents.

4.1.3 Summary and Conclusion

In conclusion, Goldwind represents successful Chinese wind manufactures that try to obtain most updated technology and enlarge its market share both domestically and internationally. Similar patterns appear when we study how Chinese wind manufactures obtaining their core technology, although slight differences exist in detailed cases. Back in 1980's and 1990's, technology was gained mainly through foreign government donation or equipment import using foreign governmental loans. Although in-house innovation has always been supported by the national research plans, the poor innovation capacity in firms still could not allow them to gain cutting edge technology through indigenous innovation. 2000's saw technology gaining pattern changing to a commercial merge model: Chinese wind manufactures used the profit they gained in wind equipment manufacturing to purchase R&D labs, companies with design capacity or licensing most updated technology from international competitors. This trend gradually ended recently for no mature technology is available for purchasing or licensing anymore. Chinese wind energy firms, actively or passively, turned to the strategy of indigenous innovation.

A clear direction of importing technology, commercial merge, and indigenous innovation illustrates the innovation path Chinese wind energy experienced during the past 30 years.

4.2 Jiuquan Wind Farm Construction – the large-scale deployment project in China

4.2.1 Background information of Jiuquan Wind Farm

Located in northwest of China, Gansu province is one of the provinces having rich wind resource. Jiuquan City locates at the west part of Gansu province, next to the border of Xinjiang province. Jiuquan has land area of 19.2 km^2, with potential wind resource of 210 GW and available storage of 82GW at present. It is geographically and climatological appropriate for large-scale, concentrated wind farm construction.

Jiuquan Wind Base was the first wind base over 10 GW being constructed among the seven state planned wind bases. In May 2008, NDRC approved constructing scheme of Jiuquan Base in the 11th Five-years Plan. At stage I, four wind farms with 3.8 GW designed capacity were under construction in Changma, North Bridge, Ganhekou, and Qiaowan. In 2009, another 16 wind farms of the stage I project started construction. By the end of 2011, 3600 MW capacity had been installed and connected to grid with 200 MW still under construction. With the smooth advance of Jiuquan I stage programs, NDRC started to plan for the stage II project with 5 GW designed capacity. In May 2011, preparatory work of Jiuquan II stage had been approved by National Energy Bureau. By the end of February 2013, the program passed the test on technology and was ready to begin.

The 10 GW Jiuquan Wind Base was scheduled in two stages. At stage I, 5500MW was finished in 2010. The stage II is gaining the construction approval through NDRC. For each stage, different wind farms in different places in the wind base will be constructed. For example, North Bridge is a site spot with good wind resource. There are three main wind farms at stage I owned by State Development & Investment Corporation (SDIC), China Power Investment Corporation (CPI), and HydroChina respectively. North Bridge SDIC Wind Farm installed 66 1.5MW turbines manufactured by Dongfang Electric. The project construction started in 2009, and it connected to grids in 2010. By the middle of 2012, it had totally generated electricity 410 million kWh. CPI Wind Farm adopted 200 0.75 MW turbines manufactured by Goldwind in the first and second stages. In its third stage, it installed 134 1.5MW turbines manufactured by Sinovel. HydroChina Wind Farm was begun in 2009, installing 67 Goldwind 1.5MW turbines and 67 Sinovel 1.5MW turbines. The project was connected to grids at the end of 2009, and had generated 4.87 million kWh by the middle of 2012. For each wind farm, there are detailed schedules for the second stage construction. For each wind farm, project concession is held. The open bidding process attracted different equipment manufactures, electricity companies independently or jointly. For example, Sinovel got 1800 MW contract at the first stage of Jiuquan Wind Base construction.

4.2.2 Deployment innovation path in Jiuquan wind base

According to data from local governments in Gansu and the investigation by CAE, Jiuquan Base massively installed domestic 1.5 MW turbines, supplemented with a few foreign larger turbines. The wind base started construction around 2008, which was the time when domestic manufactures started producing 1.5 MW wind turbines. Compared with foreign products, domestic turbines are cheaper and are more adaptive to the local environment. Therefore, although foreign turbines are of larger size, these characters made domestic turbines become mainstream equipment in early stage development of China’s large-scale wind energy. With the increasing scale of wind farm construction and rising standard of technological stability and security, foreign companies, such as Vestas and Gomesa, involve more into large-scale wind farms construction. Both foreign companies and technique experts believe that foreign turbines would be more competent in China wind market due to its life-cycle cost advantage.

4.2.3 Technological difficulties in Jiuquan wind base

The main problems existing in Jiuquan Wind Base and other large-scale wind deployment is the electricity storage and transmission. Majority of the electricity generated in the wind base was transmitted out to Lanzhou, the capital city of Gansu province 1000 kilometers away through a 750 KV line. This line was built in 2010 when the total generation capacity in Jiuquan was only 1390 MW. With 4030MW wind energy generation capacity in 2011, this 750 KV transmission line was far from enough.

Besides the technological difficulties of grid connection mentioned before, other technology challenges exited in Jiuquan Base. Gansu Province. Unlike some European country, does not have consistent wind resources. Wind resource prediction technology is greatly needed to make better use of the resource and to connect to the grid with enough control of the grid. In this sense, no existing technology could be borrowed since China has various wind distribution that no other country ever encountered. Off-grid accident also happened when wind farms could not pass the Low Voltage Ride Through (LVRT) test. The LVRT technology has been conquered by top foreign manufacturers, especially in small-scale wind turbine application. However, Chinese turbines can only passed tests in laboratory. In practice, turbines are often obsessed by unstable wind power and grid situation.

4.2.3 Summary and Conclusion

In conclusion, Gansu Jiuquan Wind Base is a typical model reflecting the special way and problems of large-scale wind energy development in China. Large-scale wind farm requires systematic innovation that combines wind turbine manufacture, electricity generation, and grid connection together. The weakest link would destroy the whole deployment process. Without carefully verification process, the large-scale deployment pattern was selected mainly from geographical and resource quality consideration. Easy selection and quick development generated many obstacles later on. Some are technological, while others are with regarding to the electricity administration mechanism in China.

Concurrently, three main technology breakthroughs are expected to further development the large-scale deployment pattern. For wind turbine manufacture, LVRT standard is essential, which would ensure the stability of the electricity generation and reduce large-scale abandon. As for the grid connection part, wind energy relied on state grid system heavily. It is the grid that decides which wind farm and sale electricity to it. Therefore, to transmit wind electricity to grid that is short of energy supply, or provide stable electricity supply are two main technological targets for wind farms. To gain local support for wind farm construction is also quite essential in China. Public opinions as well as local government taxations are two main concerns (Dai and Xue, 2014).

4.3 Hui Teng (HT) Blade Design and Manufacture Case

4.3.1 Background of Hui Teng Blade

HT is a world-class wind blade producer of China. HT was founded in Baoding Development Area of High-tech Industry in 2001, held by Baoding Huiyang with share 45%, China Aviation Group with share 30% and US Meiteng with share 25%. HT's business began with producing 600 kW wind blades based on imported technologies, which was sponsored by a national innovation program during "The 9th five-year plan" (1996-2000). The success in 600 kW wind blade production made HT the first Chinese enterprise having independent production capacity. But HT still lacked accumulation of core technologies, and could hardly find suitable foreign alliances for innovation cooperation. HT continued to develop 600 kW and 750 kW wind blades based on imported technologies, and focused on developing customized products that meet the specific demands in China such as low temperature and dusty environment. These endeavors made HT a strong competitor in local market. HT then began to work with their foreign alliances (e.g. CTC in Netherlands), and used the advanced design to develop large-scale and advanced wind blades. In 2005 and 2006, HT successively launched 1.2 MW and 1.5 MW wind blades. When Chinese government set localization and innovation goal for wind industry in early 2000's, HT's market share increased quickly and reached 90% in 600 kW sector in 2006. All these achievements set HT's position as the leader in China's market and a significant player in global market. After 2006, HT set off with its new globalization strategy. On material provision, HT controlled the cost through collaborating with Germany Degussa Company. On wind technology, HT bought out Holland CTC in 2009 and then acquired abilities of top technological innovation and worldwide service provision. With the achievements of global strategy, HT continued its progress in innovation and production. In 2007, after launching its 2 MW blade, HT further narrowed the gap between domestic producers and foreign producers in unit capacity. In 2009, HT's amount of provision successively breakthrough 6000 and 7000 units. There had been 8 counties, including US, Japan, and South Africa, adopting HT's products. Up to now, HT has products covering 11 series, 29 types of blade in total. HT is focusing on R&D of 5 MW offshore wind blade at present.

Government interventions played a significant role in China's wind market boom, as well as the growth of the local firms' innovation capabilities. HT, as a representative case, benefits not only from their endeavors, but also from intervening policies both at central and local government level.

4.3.3 Key elements for HT's technological innovation path

R&D supportive policies

HT was not able to develop their innovation capacities without government's R&D support, especially in the initiative stage, when its technological capacity was weak.

In 1999, as an aviation propeller manufacturer, HT undertook national key scientific and technological project - 600kW large wind turbine blade research. The first prototype blade was produced in May 2000 and lowered the price down to 46% (Interview Hui Teng, 2012). After that, HT applied for funding from National Torch Program (Huo Ju Ji Hua) for the commercialization. In April 2001, HT's 600kW blade entered the mass production period, which ended the time when China totally relied on import blades.

Throughout all important stages of HT's development, including its 750kW, 1.2MW, 1.5MW, 2MW and 3MW wind turbine blade design and manufacture, national and local R&D programs played essential roles. Table he following is a list of R&D projects undertook by HT.

Table 10 Major research project supported by the government in Huiteng

<table>
<tr><th>Code</th><th>Project period</th><th>Objective of R&D subsidy</th><th>Funding Organization</th><th>Technology</th><th>Date</th></tr>
<tr><td>**PR1**</td><td>1995-2000</td><td>The blade design for 600kW wind turbine system</td><td>Ministry of Science and Technology (MOST)</td><td>0.6MW</td><td>2001.4</td></tr>
<tr><td>**PR2**</td><td>2003-2005</td><td>The blade design for 1 MW wind turbine</td><td>MOST</td><td>1.2MW</td><td>2005.5</td></tr>
<tr><td>**PR3**</td><td>2004-2006</td><td>The blade design for 1.3MW wind turbine</td><td>MOST</td><td>1.5MW</td><td>2006.5</td></tr>
<tr><td>**PR4**</td><td>2006-2009</td><td>Blade (Onshore) for 1.3MW wind turbine</td><td>MOST</td><td>1.5MW （onshore）</td><td>2007.8</td></tr>
<tr><td>**PR5**</td><td>2006-2008</td><td>Blade for 2.0MW wind turbine</td><td>He Bei Bureau of Science and Technology</td><td rowspan="2">2.0MW</td><td rowspan="2">2007.10</td></tr>
<tr><td>**PR6**</td><td>2004-2006</td><td>Huge-size wind turbine blade</td><td>MOST</td></tr>
<tr><td>**PR7**</td><td>2006-2008</td><td>Monitor technology of wind turbine blade</td><td>MOST</td><td rowspan="5">2.5MW、3.0MW</td><td rowspan="5">2009.2</td></tr>
<tr><td>**PR8**</td><td>2007-2010</td><td>The technology of advanced wind turbine airfoil</td><td>MOST</td></tr>
<tr><td>**PR9**</td><td>2007-2009</td><td>Moulding of Huge-size wind turbine blade</td><td>State Commission of Science and Technology for National Defense Industry</td></tr>
<tr><td>**PR10**</td><td>2007-2009</td><td>Blade for 2.5MW wind turbine</td><td>Baoding Bureau of Science and Technology</td></tr>
<tr><td>**PR11**</td><td>2009-2011</td><td>Blade for 3.0MW wind turbine</td><td>Baoding Bureau of Science and Technology</td></tr>
</table>

Source: Interview from HuiTeng.

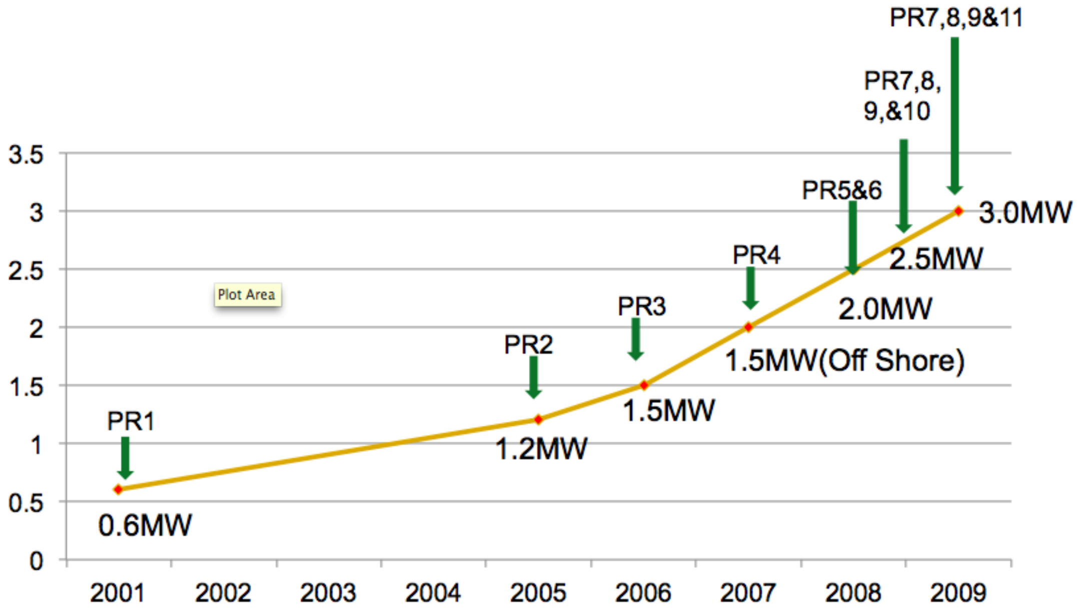

Figure 10 Key support from governmental R&D project to HT

Source: Governmental Policy Data Center, Tsinghua University

Taxation and finance policy

Chinese central government used taxation policy to promote wind energy. In 1997, the State Council reduced value added tax for joint ventures and multi-national companies in energy, and reduced the import tariff to stimulate the imports of advanced foreign wind technologies. In 2000, the government further exempted from tariff and import value added tax on wind power equipment for large-scale wind turbines. It also decreased the value-added tax levied on gird-connected wind power from17% to 8.5%. In 2001, 50% of value added tax in wind energy generation process was cut off to encourage the establishment of joint-ventures in China. The import tariff rate had been adjusted in 2005 and 2006 to encourage imported parts for local assembling. When it came to 2008 the Chinese firms become comparatively competitive, the government removed restrictions on import tax rebate and gave it to the national-level agencies and later removed the tax policy intervention on the wind energy industry.

The finance policies are rarely used directly by central government, in 1999, the Notice of Further Support for Renewable Energy to advance renewable energy offered discounted loans for renewable energy projects. However, local government use it more often. For example, Baoding issued China Electricity Valley bond and strived for national and provincial level projects to invest on Baoding's wind industry.

Localization policy

In 2003, The Wind Power Concession Project, issued by the National Development and Reform Commission, set a mandatory minimum of localization rate for newly installed wind turbine, at least 50% in 2003 and 70% after 2004. From 2003 to 2007, five rounds of concession projects had been carried out, totaling 3350MW cumulative installed capacity, which significantly improved the level of localization rate and promoted the utilization of wind energy resources by creating the huge market demand.

Then, China repealed the regulation on localization rate in 2009. "There was no need for localization requirement anymore after 2009", said Gao Hu in the interview "because all Chinese turbines meet the requirement naturally. And foreign turbine manufactures set up local production lines to meet the requirement as well".

Other policies

The government also introduced a series of policies to promote the rapid, long-term and healthy development of the wind power industry, such as the Renewable Energy Law (NPC, 2005), the Mid- and Long-Term Plan for Renewable Energy Development (NDRC, 2007)and the Eleventh Five-Year Plan for Renewable Energy Development (NDRC, 2008). The government also aimed to establish the wind power industrial service system, equipment standards, a testing and certification system, and national wind turbine and spare part R&D centers through the Document on Promoting Wind Power Industry Development (NDRC and MOF,2006)

4.3.3 Summary and Conclusion

Based on HT's case, we can indicate that, in the context of global innovation, China's wind policy has a profound impact on wind industry ranging from direct R&D support, moderating import and localization, and constructing a market-oriented environment for competition.

In the early stage of HT, the central government R&D funding support was the main driving force of its development. From the late 1970s to 1995, there were, major support for wind turbine manufacturing came from R&D subsidies. HT benefits from these national projects and quickly became a leading in wind turbine blade manufacturing in China. In the second stage, HT established partnership with a German company on blade design over 1 MW turbines, as well as making close partnership with a Holland company on the contractual basis. In June 2006, HT's 1.5MW blade was successfully produced, which makes HT have a clear development direction establishing HT's leadership in China wind power market. In third stage, enterprise internationalization and R&D globalization became the main trend and HT Acquired the Holland company CTC for blade design capability enhancement.

Chapter 5: Discussion/Conclusion

In this report, research evidences have been elaborated to answer the key research question of what are the key technology trajectories in Chinese wind energy industry and what are key influential factors leading to these trajectories. Three conclusive points have been found to contribute to the explanation, which may lead to further research in the future.

5.1 Internationalization as a main method leading to innovation path

The way Chinese wind energy industry got its technology improvement does not like the way EU wind industry did, neither like Indian wind industry did. The trajectory event is influenced by features of the wind energy industry and China's development context.

Wind energy industry both contains production process locates at the lower end of the value chain and upper level of the value chain. Tower manufacture, for example, is simply mechanical engineering process that has very little technology value-adding in it. On the other extreme, blade design, turbine design and manufacture, and control system design are all high-tech featured. Therefore, it does not require strong technological background to enter into the industry, but it does require strong technological capacity to lead the industry.

China started its wind energy industry in a way similar to how it started other manufacture industries, such as toy manufacture. Importing production lines, gaining international market share via low price (with low quality product for most of the time), and gradually gained the core technology capacity to move upwards towards higher end of the value chain. Meanwhile, since Chinese wind energy industry started to grow in late 1980's, it also learnt lessons from other manufacturing industries. For example, Chinese knew that the industry would have low resistance to uncertain if the core technology is not obtained. Therefore, the goal for advanced innovation path was very clear: indigenous innovation capacity was the ultimate goal for Chinese wind energy industry. It could be achieved through self-R&D, technology transfer, or commercial merger. China had tried all three of them. First of all, China was the "late comer facing a fast growing market" in wind development, and this makes it impossible for it to rely on self R&D to standing in the first tier. China also tried technology transfer, however, this method has embedded short comings within it – a company or a country can never be leader by using transferred technology without strong self-R&D capacity. Commercial merger can solve this problem to some extend. On the one hand, commercial merger can greatly narrow the technology gap between the purchaser and the acquired. Secondly, purchasing a research design company or a company with strong R&D capacity would increase research competitiveness in the future.

China now stays at the stage of another potential innovation path, in which more domestic companies would push the development of the wind technology by self-R&D. A recent example was: Goldwind, which is the wind turbine manufacture that has the strongest R&D capacity in China regained its market leading place in 2011 and 2012, while its largest competitor, Sinovel, lost the leading position due to fast expansion and less R&D capacity.

5.2 Long-term policy guarantees Chinese wind technology trajectories

Besides detailed stimulation policies, the overall national strategy on renewable energy development also effectively ensures investment in wind energy industry. China started its development strategic adjustment right after 1993 when Kyoto Protocol executed. Ever since then, the design and implementation of low-carbon development has been repeated expressed in various policies. This long-term stable policy framework set up the strongest guarantee for domestic and foreign firms to invest in the technology and the market.

Foreign wind firms were highly motivated by these consistent wind policies in China. "Long-term policy supporting wind energy development makes us (Vistas China) not worry about future market. For example, the 2020 target of emission reduction, different five-year plans, renewable energy law and many national development targets set up the policy framework to ensure a quick development of the industry here in China" (Tom Pellman, Government Relationship Department, Vestas, China). Starting from the Renewable Energy Law of 2006, Chinese renewable energy policy is unlikely to be implemented with discount or even be canceled. Therefore, strong confidence towards the Chinese market made foreign wind companies invest more on local R&D and marketing exploration. During the "down time" of Chinese wind market around 2009 and 2010, no foreign wind firms reduced their input in China for the sake of the future market competition.

5.3 Assorted policy instruments on indigenous innovation

Government interventions are viewed as effective measures to expedite the innovation process of an emerging technology starting from early-stage development. In China, government interventions in wind energy appeared to be a range of innovation policies. This package of policy instruments includes R&D activities, market exploration policies, strategic agenda, tax and financial policies, technology standards to shape innovation capabilities, and incentives to attract private investment. These policies were adopted at the different developmental stage of Chinese wind industry, targeting to create the largest wind market in the world, and to influence the technology trajectories. Comparing with national policies in EU and India, the context of the package is highly alike.

The effective package of policy covers three stages of wind technology development. Firstly, climate technology could rarely form mature market at the beginning; therefore, it is necessary for the government to intervene to form the initial market. At the embryonic stage of wind energy, Chinese government focused on the manufacturing capacity by encouraging production line import. Subsidies and taxation deduction were set to encourage imports of wind technologies. With almost no domestic market back in 1980's, commercialization policy (i.e. demonstration projects) functioned as the initial market formalization tool. When China took its effort enlarging domestic market, more policies were adopted, such as the five rounds of concession projects. Detailed policy tool were selected considering specific country context, such as the wind resource distribution, quality of the wind resource, technological base, share of the state-owned enterprise, etc.

Secondly, when the climate technology market emerged, government started to adopt normal policy packages. For example, R&D may stimulate research capacity to generate technology push effect; tax incentives, national energy policy and environment regulations may generate market pull effect; technological standards can set fair competitive environment for the market. At this stage, climate technology should be encouraged just as other important technologies should.

When we observe the "uniqueness" of Chinese wind energy technology trajectories, we are observing the first stage of its development. As the industry as well as the market turned to mature, similar technology trajectories are expected to appear. This process might be stimulated by the internationalization pace different firms are experiencing. Emphasizing advanced technology, high quality, fair competitions are shared values among all competitors in the wind energy field all over the world.

In 2013, China has restructured the energy authority by combining The Energy Bureau and The State Electricity Regulatory Commission. The new agency emphasizes the significance of wind industry, and stresses the development strategies including technology trajectories. In addition, the new agency commits to work with relevant ministries to increase R&D subsidies on renewable energy, and hopefully many specific technologies will be developed to complement large-scale wind farms in the northwest, in order to deal with the wind abandon and grid connection dificulties. On the other hand, many firms in China (incl. foreign firms) will also benefit from the government's plan on building distributed networks in the southeast of China, as well as the plans of building offshore wind farms.

To date, China's wind energy industry was not a linear research-technology-product-market process like those in developed economies. Government interventions played a significant role in building the largest wind market, in the catch-up of innovation capacities, as well as in developing China's specific technology trajectories.

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