A REGIONAL-POWER-GRID-BASED WIND POWER FEED-IN TARIFF BENCHMARK PRICE POLICY IN CHINA

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A Regional-power-grid-based Wind Power Feed-in Tariff Benchmark Price Policy in China

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A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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Certificate of Originality

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ABSTRACT

This thesis has completed a comprehensive policy design process for the reform of the wind power Feed-in Tariff (FIT) benchmark price in China. This thesis consists of five chapters. A series of main supporting policies implemented by the government from 2009 to 2016 is summarized in Chapter One. This chapter aims to provide a systematic overview of the evolution and implementation of onshore wind power development, as well as analyse the localization and competitiveness of wind power enterprises. This chapter summarizes how the Chinese government efficiently promotes the drastic wind power development by means of fiscal and non-fiscal policies, which includes stimulating the wind power investment, addressing the wind power curtailment problem, localizing the Chinese-owned manufacturers in domestic markets and internationalizing the exposure of Chinese-owned enterprises. This chapter concludes that the effectiveness of wind power policies is high, and they play a vital role in the Chinese wind power market. Chapter Two aims to examine the effectiveness of the current wind FIT policy at a national-level, and to investigate the determinants of wind power development at a regional-grid-level. The determinants include substitutable fuel (coal consumption), economic development (GDP per capita), residential electricity price and efficiency of an economy (electricity intensity). It is found that the determinants on wind power development show great differences among six regional grids. It is also found that it is urgent to reform the wind FIT policy, especially segmented wind FIT policies rather than a national consolidated one should be developed for different regional grids. Chapter Three establishes the wind power FIT policy design framework and narrows down the design elements by cross-sectional analysis. Chapter Four evaluates the model developed in Chapter Three in detail. The Chinese government plans to adopt a low or no subsidy policy mechanism on renewable energy power development in the future. To achieve a balance between reducing financial burden on the government and ensuring profitability of investors as well as to account for the regional differences in China, a novel regional wind power grid feed-in tariff benchmark price

mechanism by Net Present Value (NPV) method and Real Option (RO) method is proposed in this chapter. The results voice support on the appropriateness of gradually decreasing the wind feed-in tariff (FIT) benchmark price to as low as the coal-fired FIT. The proposed FIT price level is presented as a price range on the basis of a guaranteed Internal Rate of Return (IRR) between 8% and 15% for wind power investors. The results indicate that the current FIT price should be readjusted and redistributed. Although the FIT price in Central and South China grids is recommended to be relatively high, the NPV of wind farm project value in six regional grids are at the same level. Policy implications, research limitations and future work are summarized as conclusions in Chapter Five.

PUBLICATIONS ARISING FROM THE THESIS

[1]**Zhang, R.X.X**, Ni, M., Shen, G. Q. P., & Wong, J. K. W. (2019). An analysis on the effectiveness and determinants of the wind power Feed-in-Tariff policy at China's national-level and regional-grid-level. *Sustainable Energy Technologies and Assessments*, *34*, 87–96. https://doi.org/10.1016/J.SETA.2019.04.010

[2]**Zhang, R.X.X.**, & Shen, G. Q. P. (2019). The relationship between energy consumption and gross domestic product in Hong Kong (1992 – 2015): Evidence from sectoral analysis and implications on future energy policy. *Energy and Environment,* (June 2019). https://doi.org/10.1177/0958305X19854542

[3]**Zhang, R.X.X.**, Shen, G. Q. P., Ni, M., & Wong, J. K. W. (2018). Techno-economic feasibility of solar water heating system: Overview and meta-analysis. *Sustainable Energy Technologies and Assessments*, *30*, 164–173. https://doi.org/10.1016/J.SETA.2018.10.004

[4]**Zhang, R.X.X.**, Shen, G. Q. P., Ni, M., & Wong, J. K. W. (2019). An overview on the status quo of onshore and offshore wind power development and wind power enterprise localization in China. *International Journal of Green Energy*, *16*(15), 1646–1664.

[5] **Zhang, R.X.X**, Shimada, K., Shen, G. Q. P., Ni, M., & Wong, J. K. W. (2019). Low or No Subsidy? Proposing a Regional Power Grid Based Wind Power Feed-in Tariff Benchmark Price Mechanism in China. *Energy Policy*, 146 (November 2020). https://doi.org/10.1016/j.enpol.2020.111758.

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LIST OF ABBREVIATIONS

Abbreviation	Full name	Explanation
FYP	Five Year Plan	A series of social and economic development initiatives issued since 1953
UNFCCC	United Nations Framework Convention on Climate Change	An international environmental treaty aims to address climate change problem
CDM	Clean Development Mechanism	A mechanism under Kyoto Protocol which allows emission-reduction projects in developing countries to earn certified emission reduction credits
REL	Renewable Energy Law	China's first renewable energy law which was enacted in 2005
NDRC	National Development and Reform Commission	A macroeconomic management agency under the Chinese State Council. It holds the administrative power to manage the economic structure in China.
MF	Ministry of Finance	A department under State Council to handle financial affairs
FIT	Feed-in-Tariff	A subsidy policy which aims to encourage wind energy investment
CWEA	Chinese Wind Energy Association	A non-profit entity that aims to promote academic, technical and social connection among China and international countries
NEA	National Energy Administration	A department under the NDRC to implement energy-related policies
SGCC	State Grid Corporation of China	One of two state-owned electric utilities of China which provides electricity to North, Northeast, Northwest, East and Central China grids
CSG	China Southern Power Grid Corporation	One of two state-owned electric utilities of China which provides electricity to South China grid
SOEs	State-owned enterprises	A business enterprise where the government or state has significant control through full, majority, or significant minority ownership
NEB	National Energy Bureau	A Bureau under the NDRC that supervises and regulate the energy development issues
NPC	National People's Congress	The chief legislative authority of China
SC	State Council	The chief administrative authority of China

CHAPTER ONE

Introduction

1.1. Overview of the Wind Power Development in China

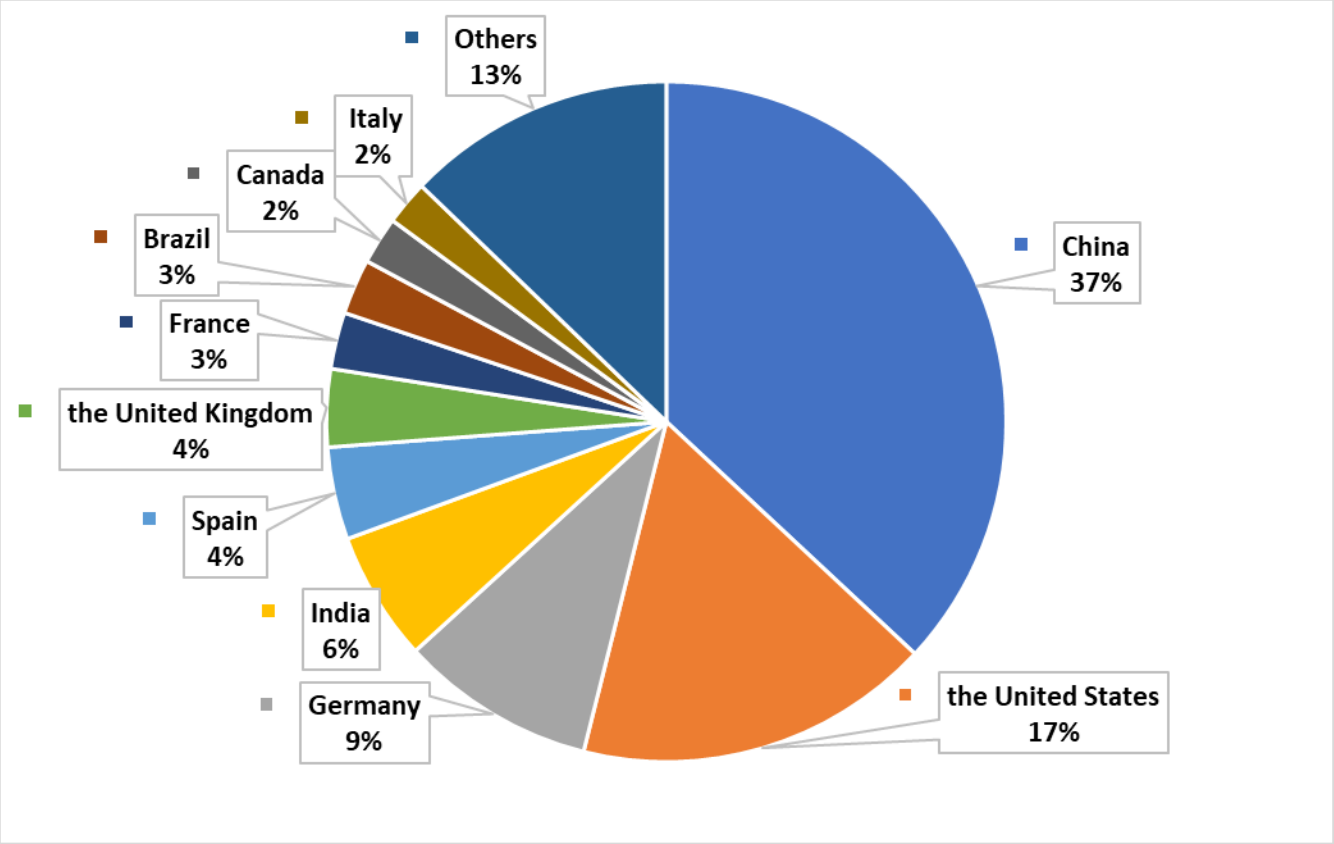
1.1.1. Global Position of China's Wind Power Development

Climate change and global warming cause negative impacts on the ecology. The most influential factor to aggravate global warming is the industrialization in the past 150 years, which has raised the average temperature of the earth's surface by 0.85°C (Handbook of Environmental and Sustainable Finance 2016). Realising that tackling the climate change problem requires the cooperation and supervision among different countries, in June of 1992, 189 countries reached the consensus to form an international treaty known as United Nations Framework Convention on Climate Change (UNFCCC). Thereafter, in 1997, Kyoto Protocol was adopted by UNFCCC and proposed the Clean Development Mechanism (CDM) that assigned duties to developed and industrialized countries, with the obligation to implement greenhouse gas mitigation projects in developing countries to achieve their specific targets in the Protocol. As a developing country, China was not required to set limits on the greenhouse gas emissions. However, the dramatically fast development of China's economy after millennium makes China the largest consumer of traditional energy and the largest emitter of greenhouse gas, which is due to China's energy dependency on coal (68.5%, in 2016) and oil (18.9%, in 2016) (BP Statistical Review of World Energy 2017). The rapid development of

China's GDP highly depends on sufficient and reliable power supply (Shen and Luo 2015). Meanwhile, renewable energy technology becomes mature in developed countries. To reduce the emission of greenhouse gas and other pollutants, the Chinese government decided to develop renewable energy to replace the air-polluting traditional energy by enacting Renewable Energy Law (REL) in 2005, and then implemented an amended version of REL in 2009. Thereafter, the National Development and Reform Commission (NDRC) has subsequently enacted a series of legislation and regulations to expand the dissemination of renewable energy, of which the subsidy and incentive policies by the Ministry of Finance (MF) are the majority.

After the implementation of a series of supporting policies, the wind power development of China has witnessed to be dramatically increased, as the total cumulative wind power installed capacity in 2018 ranks the top (Fig.1.1) among various developed countries (REN21 Secretariat, 2019).

Figure 0.1 The share amount of cumulative installed wind capacity in wind energy leading countries to theworld (worldwide total onshore wind farm installed capacity is 568.4GW in 2018).



1.1.2. Core Policies of Wind Power Development in China

Table 1.1 Summarizes the core policies that the government has implemented to boost the development of onshore and offshore wind power and the localization of wind power enterprises. The main issuers also include the State Council (SC), NEA (National Energy Association) and NEB (National Energy Bureau) besides NDRC and MF. The SC is the highest administrative organization of China. It directly supervises the various subordinate bodies in the renewable energy decision-making system, including the State Electricity Regulatory Commission (SERC), the NDRC, the MF and the Ministry of Science and Technology (MOST). The SERC supervises the electricity system of the state. The National Energy Leading

Group and the NDRC are two major institutes under SC to formulate renewable energy price measures. The MF is the national executive agency which administers macroeconomic policies and the national annual budget and at the same time handles fiscal policy, economic regulations and government expenditure for the state (State Council 2014).

Table 1.1 Core wind power supporting policies implemented by the government.

Policy	Issuer	Year	Objectives
the *Notice on Improving Wind Energy Generated Electricity On-grid Power Tariff Policy*	The NDRC	2009, 2014, 2015, 2016, 2017	Gradually decrease the wind FIT benchmark price in areas located in four wind resource categories. From 2009 to 2018, the wind FIT benchmark price in areas in Category I has been deducted from 0.51 CNY/kWh to 0.40, areas in Category II has been deducted from 0.54 CNY/kWh to 0.45, areas in Category III has been deducted from 0.58 CNY/kWh to 0.49, and areas in Category IV has been deducted from 0.61 CNY/kWh to 0.57.
the *Notice on Curbing the Overcapacity and Redundant Construction of Several Industries and Promoting the Healthy Development of Industries,*	The SC	2009	Solve the wind power overcapacity problem. Improve the healthy development of wind power industries.
the *Notice on Value-added Tax Policy of Wind Power Generation*	The MF	2009	Provides favourable tax preferential incentives for enterprise income tax (EIT) and value-added tax (VAT). The *Notice* stipulated that for wind energy project in China, The VAT was deducted from 17% to 8.5% while the EIT was exempted during the first three years, and then deducted from 33% to 15% during the second three years
the *Opinions for Promoting the Internationalization Development of Strategic Emerging Industries*	The SC	2011	Promote the exportation and internationalization of wind power manufacturers.
the *Notice on Pilot Work on Carbon Emissions Trading*	The NDRC	2011	Announces seven pilot provinces and cities to launch the carbon trading scheme in October 2011, they were Beijing, Shanghai, Fujian, Guangdong, Hubei, Chongqing and Tianjin. During the pilot operation, the carbon price is fluctuated between 5-50 RMB/tCO_2e.

the *Notice of the National Energy Administration Concerning Issuing the Guiding Opinions on Energy-related Work*	The NEA	2012	Requires collecting data on wind curtailment rate and abandoned wind power in order to address relevant problems.
the *Notice on the Feed-in-tariff Policy for Offshore Wind Farms*	The NDRC	2014	Stipulates the FIT price of 0.75 CNY/kWh for the inter-tidal wind power and 0.85 CNY/kWh for the offshore wind power
Notices on Wind Power Grid Connection and Consumption	The NEB	2015, 2016	Privilege the use of wind power areas of heavy wind curtailment rate

To systematically help the readers understand the status quo of the onshore and offshore wind power development in China that is regulated and oriented by the aforementioned policies, this thesis is organised as follows: the research aims and objectives are stated in Section 2, the research methodology is introduced in Section 3, the main body is arranged in Section 4 and Section 5, and finally is it followed by the conclusion section.

1.2. Chapter Research Aims and Objectives

The key findings of the existing literature on the wind energy policies and wind energy development in China are summarized as follows: (1) At a national level, the details (laws or regulations) of national wind energy policies are provided or compared with those of other countries; (2) Installed capacity is the main indicator for evaluating the effectiveness of wind energy policies; (3) Relationship between the wind energy policies and the wind power development is not clearly described.

This work will fill the research gap in terms of the following aspects (1) The wind energy policies and the development of wind energy are based on 31 administrative areas (provinces, autonomous regions and municipalities, instead of only at a national level; (2) The timeline of the collected data is continuous from

2005 to 2018 while the previous reviews reported data up to 2012, which means that the development of wind energy during the 12th FYP and the 13th FYP is incomplete in the existing literature but is covered in the present thesis; (3) The indicators for effectiveness evaluation include not only installed capacity (both cumulative and newly added installed capacity), but also other parameters such as the amount of wind power connected to grid, wind farm capacity factor, abandoned wind power, wind curtailment rate (4) The localization and industrialization of wind power enterprises are demonstrated, including onshore and offshore wind turbine manufacturers and wind power developers (5) The competitiveness of wind power enterprises is illustrated by means of Social Network Analysis (SNA), which provides the readers a straightforward visual grasp of the competitive relationships among wind power enterprises.

1.3. Research Methodology

1.3.1. Data Collection

A series of data is collected from the official websites of government (such as State Council, National Development and Reform Commission and National Energy Association, etc), research institutions (such as Chinese Wind Energy Association), official documentation (such as Statistical Yearbook China), journal articles and the official website or reports of wind power enterprises. It should be noted that the data of province-based wind power connected to the grid, abandoned wind power and wind curtailment rate are available only from year 2013, because the National NEA stipulated the *Notice of the National Energy Administration Concerning Issuing the Guiding Opinion on Energy-related Work in 2012* (*National Energy Administration*, 2013). The wind farm capacity factor (C, in the unit of %) is then calculated by the following formula:

$$C = \coprod n/(Pt*h) \tag{1}$$

All equations should be numbered.

This theoretical formula is widely employed for simplifying the calculation process of the wind farm capacity factor in the field (H.-P. Cheng & Yu, 2013; Xu & Zhong, 2014), where $\coprod n$ denotes the amount (GWh) of generated wind power connected to grid; Pt denotes the rated wind power capacity (MW); and h denotes the total annual hour, which is equal to 8760 hours.

1.3.2. Social Network Analysis

Social Network Analysis (SNA) is a methodology that identifies correlation of participants and their performance in a social network (De-Marcos et al., 2016; Milovanović, Bogdanović, Labus, Barać, & Despotović-Zrakić, 2019). In this study, it is employed to depict the competition relationship among manufacturers and developers. SNA is able to map the flows and competition strengths among each enterprise based on their market share ranking of wind power installed capacity. The firm nature is denoted by different shapes and colors of legend, and the cumulative wind power installed capacity of enterprise is denoted by different size of legend. The links between every two nodes represent the existence of significant competitive relationships. The direction of the links indicates the competition direction of two competitors and the width of links indicates the strength of competitiveness. The data source mainly comes from the Chinese Wind Energy Association.

1.4. Status Quo of Onshore Wind Power Development in China

1.4.1. Cumulative and Newly added Wind Power Installed Capacity

The *Notice on Improving Wind Energy Generated Electricity On-grid Power Tariff Policy* stipulated by the NDRC classified China into four wind resource areas and provide Feed-in Tariff (FIT) as subsidies to the wind power developers. Zhao et al. (2016) applied fixed effect model and random effect model to analyse the policy effect on wind power generation in China and the results indicated that FIT policy had a greater impact than non-price policy. The classification criteria and historical FIT benchmark price levels are explained in Appendix A[1] and B. It is remarkable that the FIT benchmark price differentiation is a highlight of the policy and it indeed helps the government solve the regionally inconsistent problem between wind power overcapacity and electricity consumption.

Fig.1.2 and Fig.1.3 illustrate the cumulative and newly added wind power installed capacity (MW) in China from 2005 to 2018 by 31 administrative areas, respectively. Among the 31 provinces/autonomous regions and municipalities, Inner Mongolia (30,570 MW), Xinjiang (19,912 MW), Hebei (17,448MW), Shandong (14,142 MW), Gansu (13,115 MW), Ningxia (10,740 MW), Jiangsu (9,396 MW), Liaoning (8,788 MW), Yunnan (8,635 MW) and Heilongjiang (6,692 MW) are the top ten regions in terms of the cumulative wind installed capacity by the end of 2018. In particular, Shandong, Jiangsu, Liaoning and Yunnan are located in wind resource area of Category IV. The increase rate of wind power installed capacity is almost as tenfold as that in Shandong (1,219 MW) and Jiangsu (1096 MW) in 2016, Liaoning (2,425 MW), and even as much as seventy times in Yunnan (121 MW) in 2009. Before 2011, the most amount of

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[1] Appendix A introduces the wind resource areas in China, which are Category I, II, III and IV, it also introduces the six regional power grids in China (North, Northeast, Northwest, South, Central and East) classified by geographical location. The following thesis will directly use these terms.

newly-added wind power installed capacity is added to the regions located in North, Northeast and Northwest China grids. However, after 2011, plenty amount of wind power installed capacity is found to be added in the regions located in South, Central and East, such as Yunnan, Guizhou, Guangdong, Jiangsu, Hubei and Hunan. Take Yunnan and Jiangsu as examples, from 2014 to 2016, the amount of newly-added wind power installed capacity in Yunnan reaches 5,485 MW, which accounts for 64% of the cumulative wind power installed capacity by the end of 2018. The deployment of offshore wind farm in Jiangsu is a proved notable success, that the amount of newly-added wind power installed capacity is 5719 from 2015 to 2018 and accounts for more than a half of the cumulative wind power installed capacity by the end of 2018.

Figure 1.2 Cumulative onshore wind power installed capacity in China

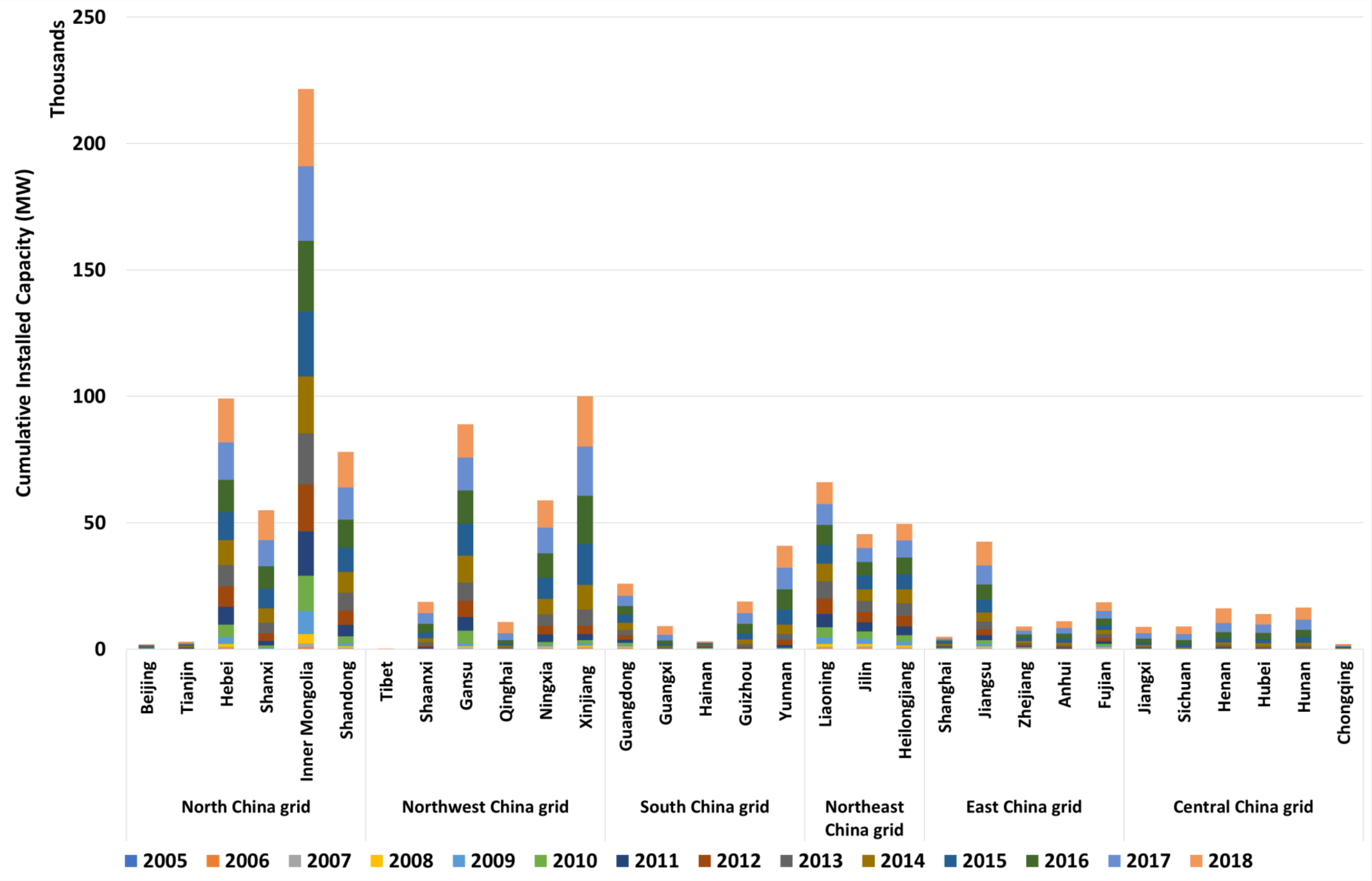
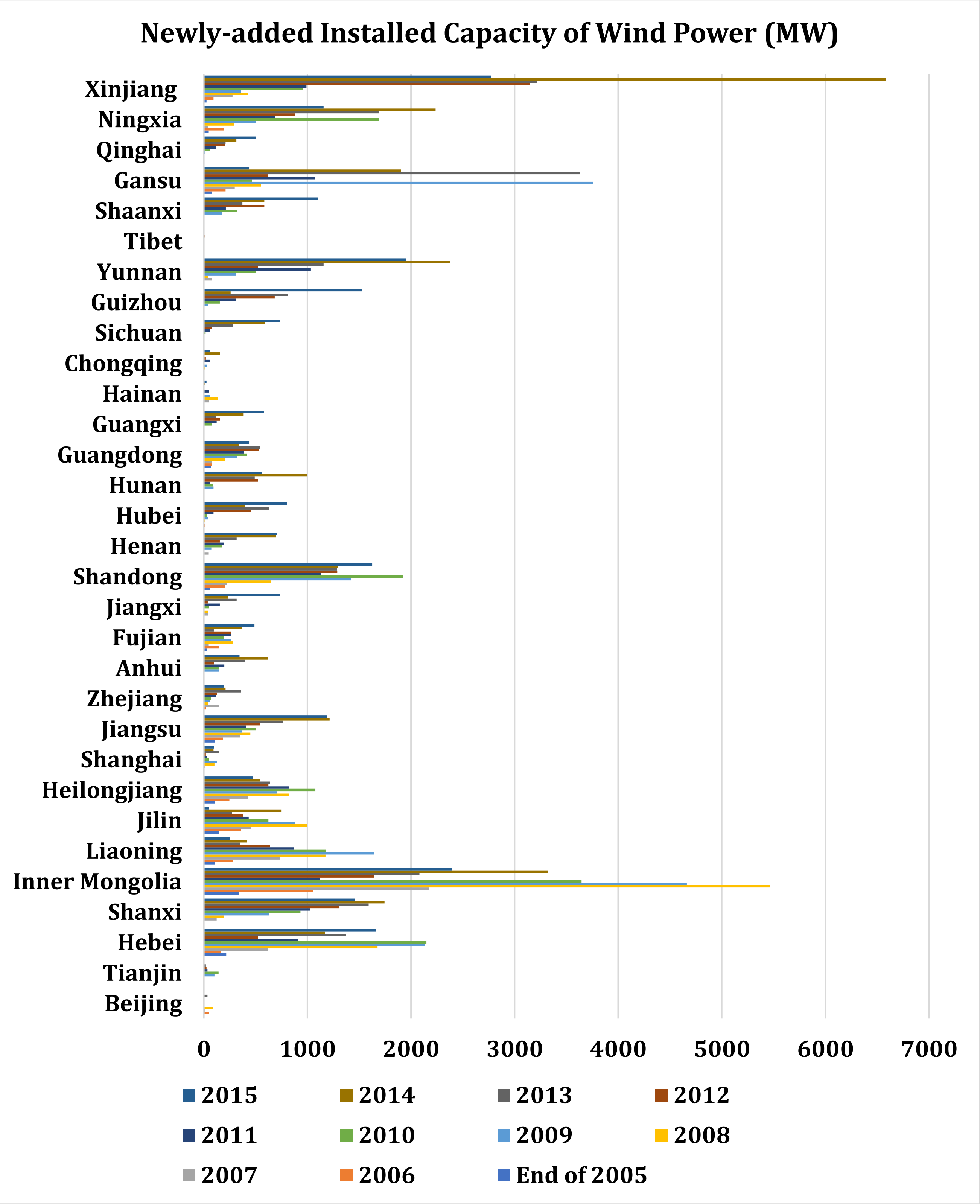


Figure 1.3 Newly-added wind power installed capacity from 2005 to 2015.



1.4.2. Wind Power Connected to Grid and Wind Capacity Factor

The impact of subsidy advantages stipulated in FIT policy of wind farm construction in the regions located in Category IV is illustrated in Fig.1.4 The share of cumulative wind power installed capacity in Category I, II and III indicates a parabolic line from 2005 to 2018, the share amount is found to be stably decreased since 2009. By contrast, the share of cumulative wind power installed capacity in Category IV increases from 28% to 50% from 2009 to 2018, and is predicted to exceed the share amount in Category I, II and III from 2019 on. The price differentiation of FIT policy has stimulated the development of wind power in poor wind resource areas, except from Jiangsu and Yunnan that are aforementioned, Guangdong (4,806 MW) and Guizhou (4,638 MW) in South China grid, Fujian (3,475 MW) and Anhui (2,629) in East China grid, as well as Henan (5,956 MW) and Hunan (4,827 MW) in Central China grid are witnessed great development. With reference to Fig.1.5 by the end of 2018, North China grid and the Northwest China grid are two leading grids with the total grid-connected wind power of 135,200 GWh and 88,610 GWh, respectively, followed by the South China grid (39,800 GWh) and the Northeast China grid (39,500 GWh). The East China grid and the Central China grid have the grid-connected wind power of 34,400 GWh and 28,500 GWh, respectively. Fig.1.6 depicts the regional electricity consumption in China from 2005 to 2017. It is found that the load centres of electricity consumption areas are clustered in North China grid and East China grid (each accounts for 24.8% of national electricity consumption), followed by Central China grid (17.6%) and South China grid (16.8%), which are non-rich wind resource areas. For comparison, the abundant wind resource areas share only around 16% of the national total electricity consumption (with Northwest China grid of 10.1% and Northeast China grid of 6.0%). Therefore, the quick development of wind power installed capacity in Category IV is expected to balance the inconsistency between wind power generation and grid power planning, which could release the electricity generation burden in load centres.

Figure 1.4 The proportion of wind power installed capacity in four categories to the national total wind power installed capacity from 2005 to 2018.

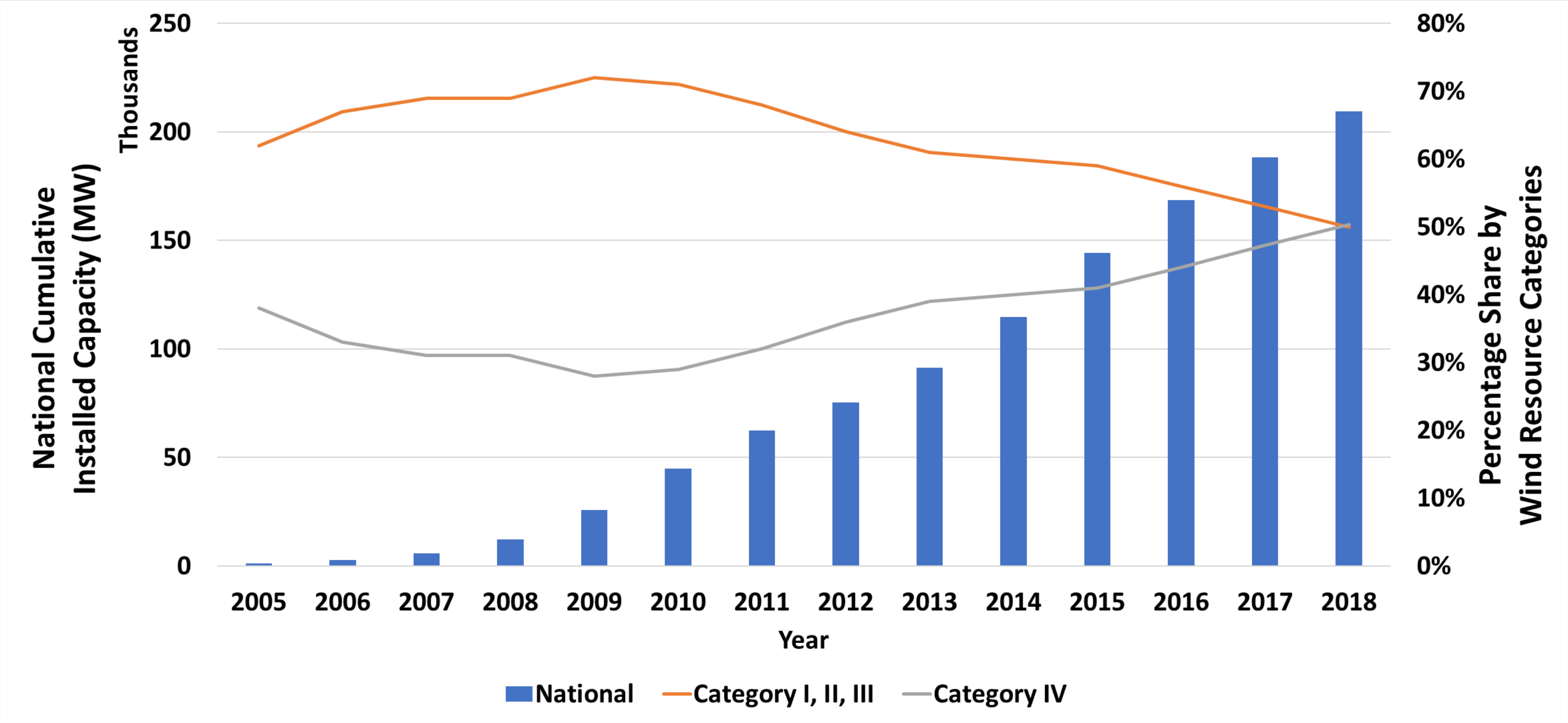


Figure 1.5 Cumulative grid-connected wind power by regional power grids from 2013 to 2018.

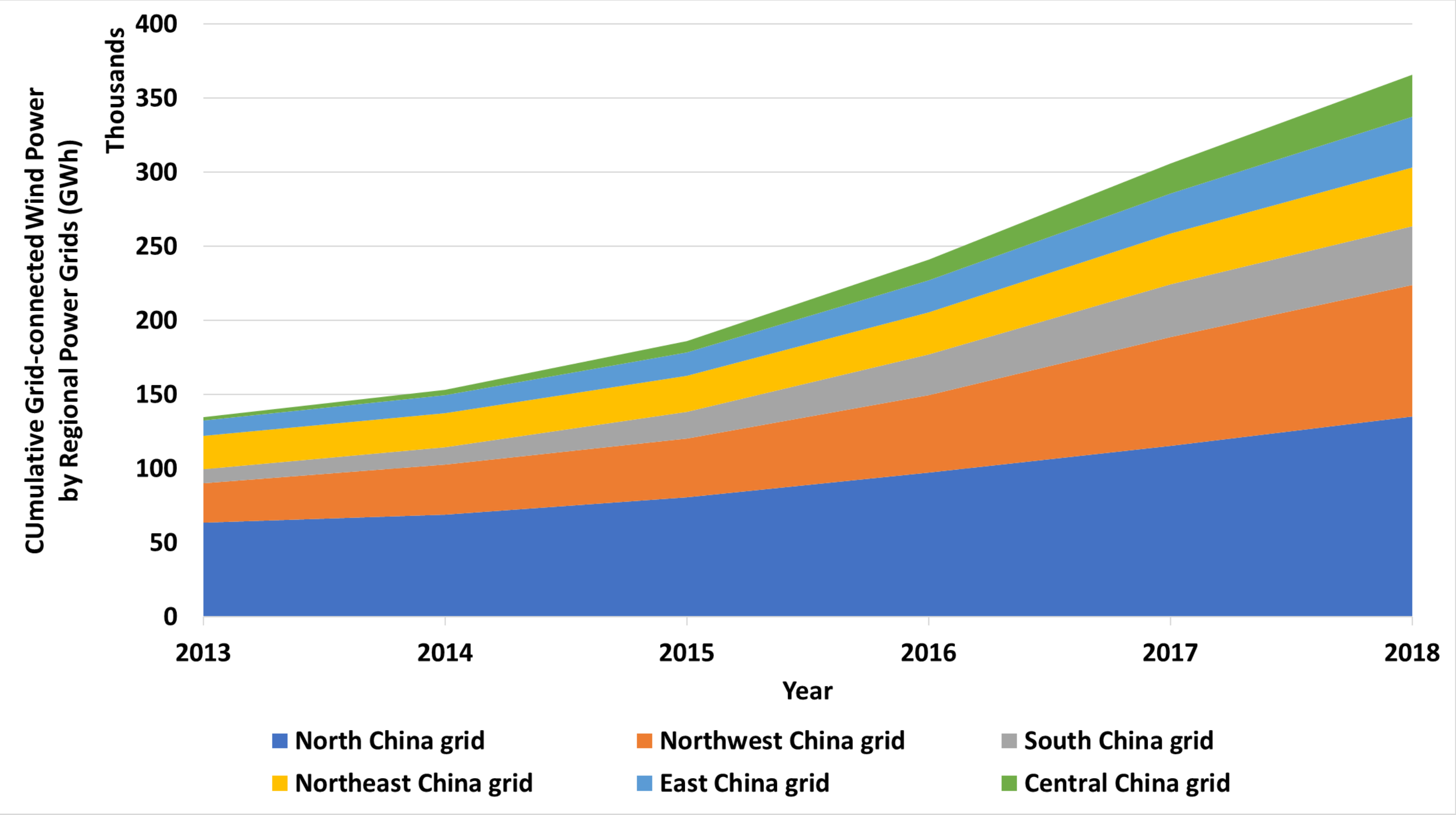


Figure 1.6 Regional electricity consumption in China from 2005 to 2017

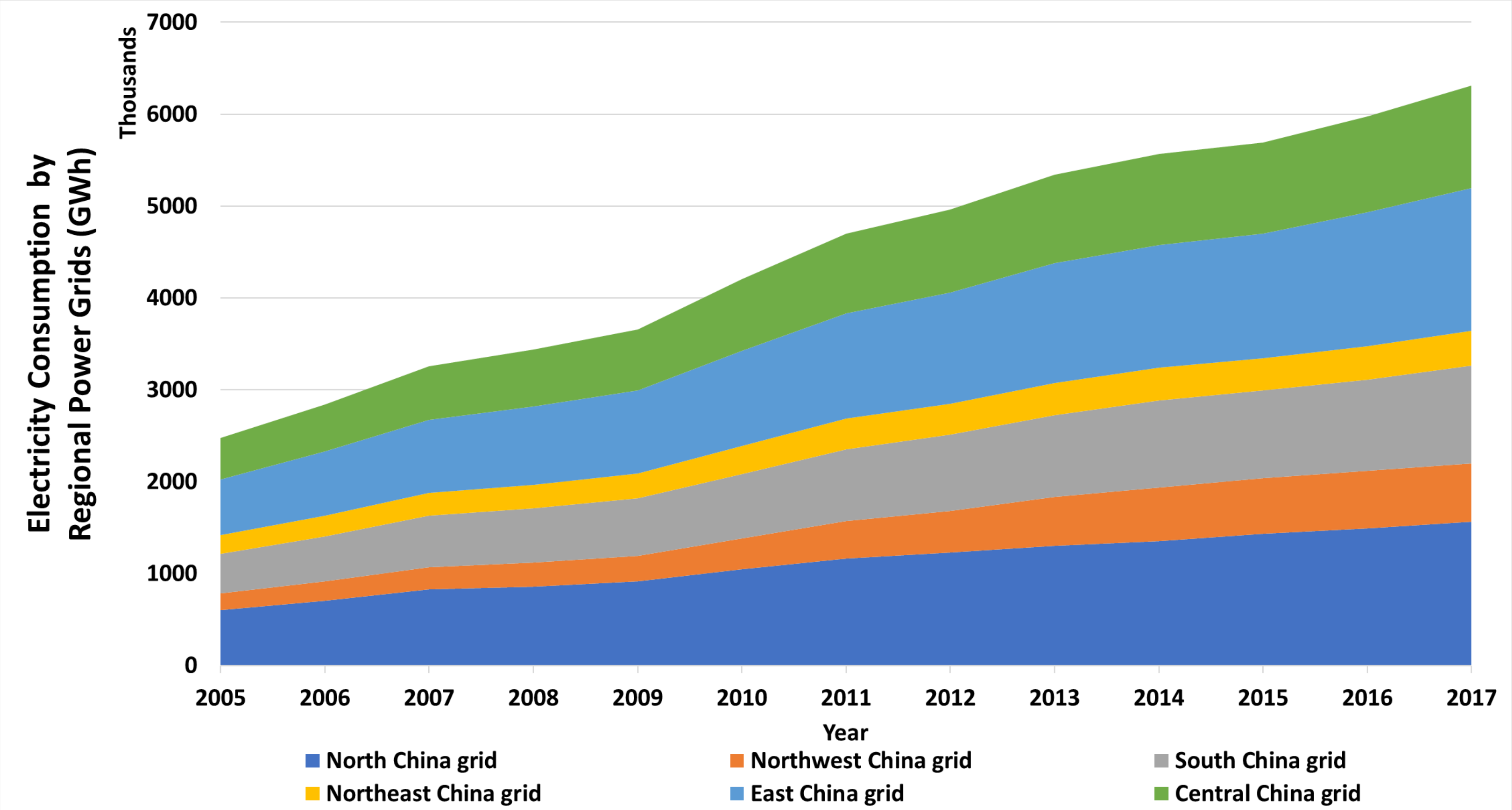


Fig.1.7 illustrates the wind power connected to the grid from year 2013 to year 2018, as well as the wind capacity factor. Fig.1.8 demonstrates the national average wind farm capacity factor change trend. It is estimated that, among 31 administrative areas in China, only four regions have an average wind farm capacity factor of higher than 20%, including Fujian (24.7%), Yunnan (22.4%), Shanghai (21.9%), Inner Mongolia (20.1%). The national average wind farm capacity factor in 2018 is only 15.9% and is even as low as 14.7% in 2015. When we look at the wind farm capacity factor by regional power grids, it is found that East China grid ranks the highest of 20%, followed by North China grid (17.7%), Northeast Chia grid (17%) and South China Grid (16.3%). Central and Northwest China grids have the lowest wind farm capacity factor as 13.1% and 12.7%, respectively. To have a better understanding of the level of wind farm capacity factor in China, this thesis compares the average wind farm capacity factor of China in recent years with those of other prominent countries that mentioned in Fig.1.1, including the United States, Germany, Spain, the United Kingdom, France, Canada and Italy. By comparison, the United States has an average wind farm capacity factor of above 32%, and the United Kingdom is of around 30%, much higher than other countries. Spain and France have an average wind farm capacity factor of around 25% and 22%, respectively. The average wind farm capacity factors of Italy and Germany are lower than those of the aforementioned countries, but still higher than that of China.

Figure 1.7 Wind power connected to the grid and wind capacity factor in China from 2013 to 2018

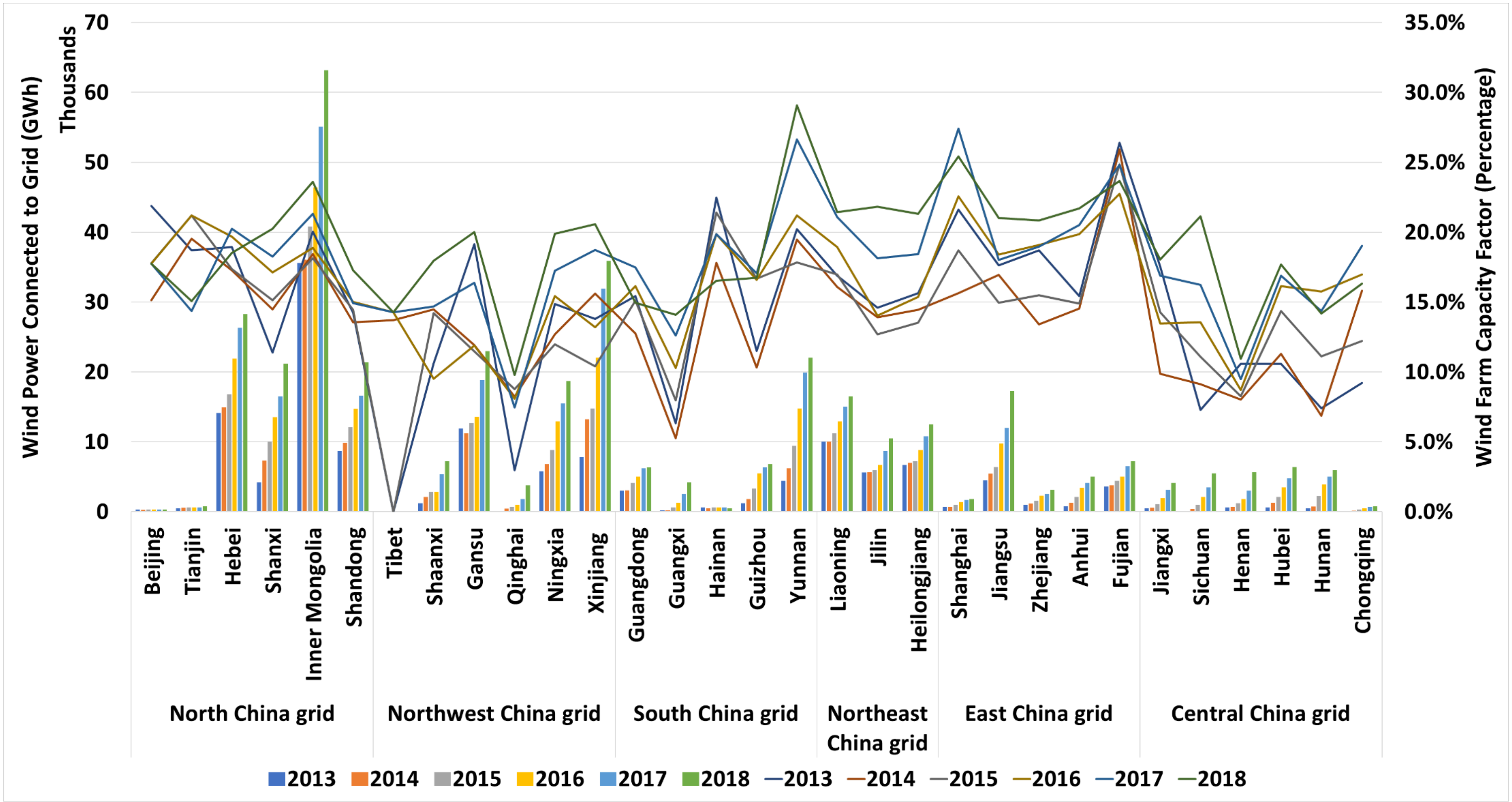
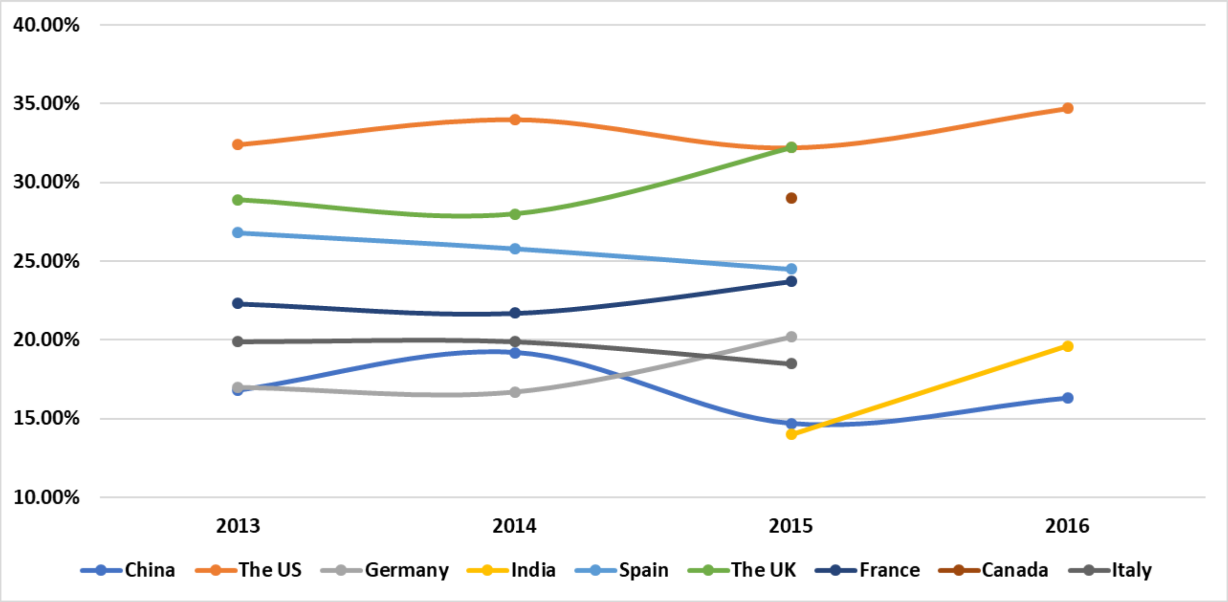


Figure 1.8 The national average wind farm capacity factors in wind energy leading countries.



1.4.3. Abandoned Wind Power and Wind Curtailment Rate

Fig.1.9 and Fig.1.10 illustrate the abandoned wind power and wind curtailment rate in specific regions from 2013 to 2018. A common reason for wind curtailment could be attributed to local network transmission congestion due to overcapacity and grid planning mismatch between grid companies and wind power developers (Gu & Xie, 2014; Z.-Y. Zhao, Chang, & Chen, 2016). In year 2013, about 16,300 GWh of wind energy was curtailed over China, or about 8.4% of total wind power production, following 20,820 GWh in 2012 (Bai, 2014). Although about 7.3% of wind generation was curtailed in 2014, the wind curtailment problem was even worse in year 2015 and 2016, with 18% and 21% of wind generation being abandoned, respectively. The wind curtailment rates are extremely severe in Hebei, Inner Mongolia, Gansu, Xinjiang, Liaoning, Jilin and Heilongjiang. Most of them are the leading regions in terms of installed capacity and are also areas with abundant wind resource. Therefore, the wind power curtailment is highly related to the wind turbine installed capacity and mainly occurs in North China grid, Northeast China grid and Northwest China grid where most of the wind farms are located, whereas the power demand is relatively low, and the transmission capacity to higher power demand regions is rather insufficient. Due to an urgent need to solve this problem, in 2015 and 2016, the National Energy Bureau (NEB) has consecutively issued the two *Notices on Wind Power Grid Connection and Consumption*, which stipulates those areas to privilege the use of wind power and cut down the wind curtailment rate. As a result, the wind power curtailment rate in 2017 and 2018 decreases heavily, which is 13.2% in 2017 and 7% in 2018.

Figure 1.9 Abandoned wind power from 2013 to 2018

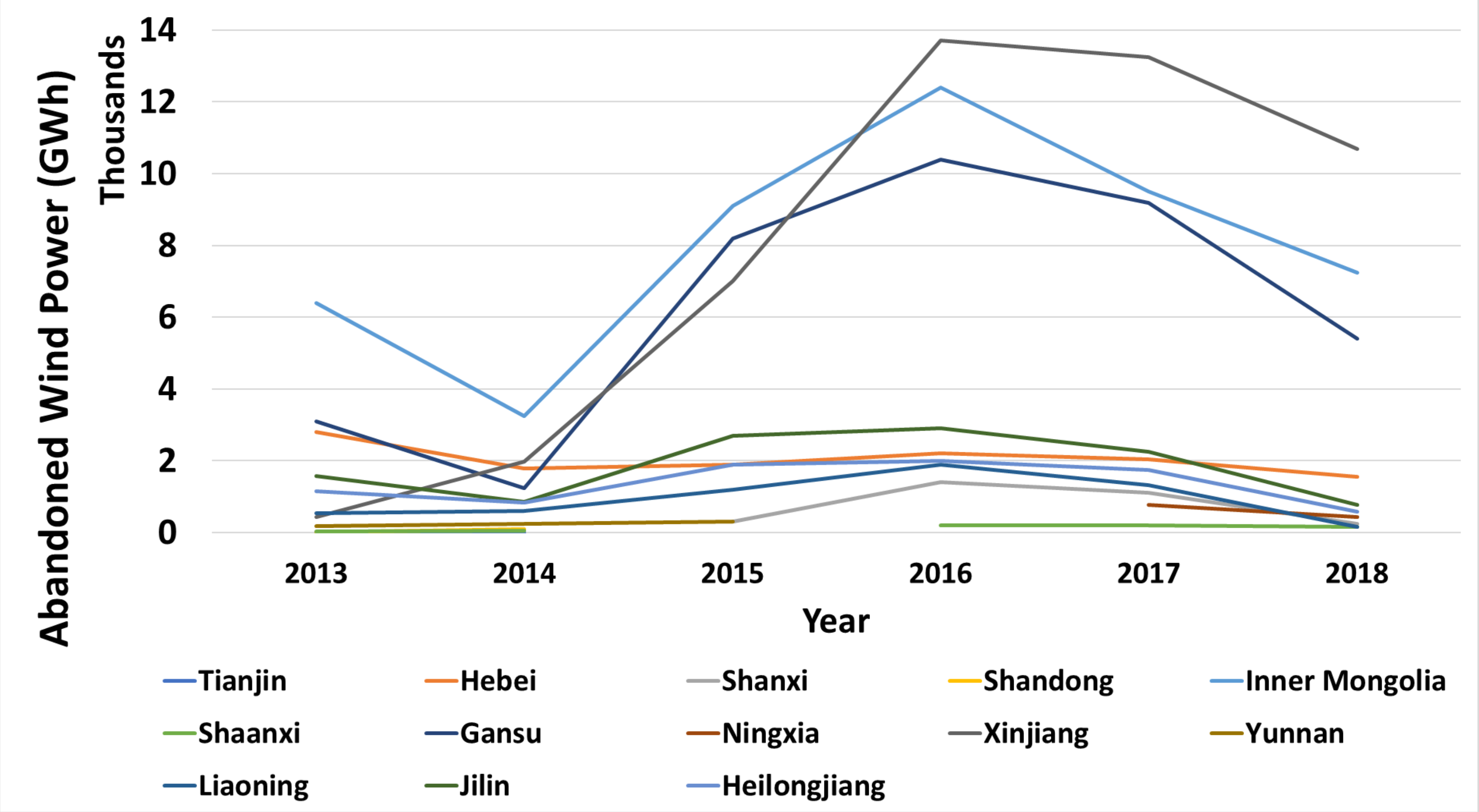
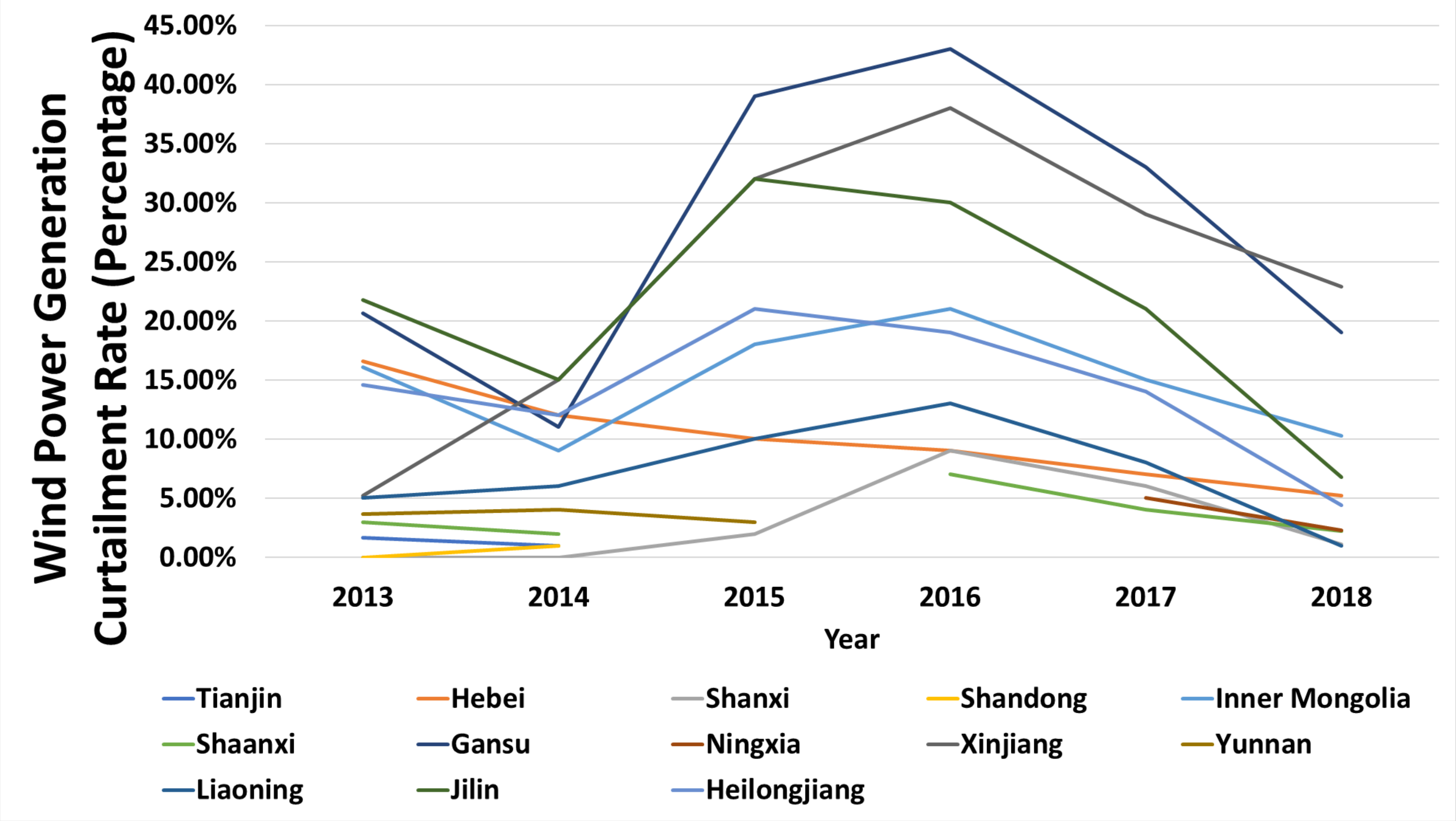


Figure 1.10 Wind power curtailment rate from 2013 to 2018



Extensive studies have analysed the causes of low capacity factor and severe wind power curtailment in China. The manufacturers, power generation enterprises, grid companies, local government and central government are main parties to be engaged in the wind energy industry in China. Shen and Luo (2015) pointed out that the central government plays the most crucial role of policy-making and affects the actors' behaviours in the wind power supply chain. Thus, the implementation and coordination rights of renewable energy development are under insufficient consideration of energy planning. However, without comprehensive power grid planning, the accommodated wind power is far less than the constructed wind power. The central government failed to coordinate the national power generation and transmission, but only meet a magnificent data of installed capacity (Luo et al., 2016; Si et al., 2011; Wang et al., 2012; Zeng et al., 2014, Luo et al., 2012). Even the attractive wind FIT incentive policy which provides subsidies to wind power investors is criticized that the fixed price determined by the government could not effectively reflect the demand and supply situation of the electricity market (Z.-Y. Zhao, Chen, & Chang, 2016). In addition, the coordination between central and local policies is hindered by excessive centralization. Local governments have to obey the command-and-control decision making system to push the development of wind power in locality. As a result, over-intervention by the local government happens all the time. Take the Jiangsu coastal wind-power industry cluster as an example, the over-intervention by Jiangsu government results in unhealthy wind power development in the local area. Under the vigorous government-led format of tax competition, performance evaluation and the quest for policy benefits (Z. He, Xu, Shen, Long, & Yang, 2016), the enterprises were directly affected by the government behaviour rather than driven by the market.

Besides, the renewable power enjoys a lower priority in power dispatch. China's power dispatch follows a coal-fired power dominated approach and capacity-based pattern. The quota of coal-fired power generators is equally assigned according to scheduled generation capacity by the local government (Wei et al., 2018; Yin, Zhang, Andrews-Speed, & Li, 2017a). For example, a 400 MW unit is equivalent to two 200 MW units. In most of the other countries, the governments utilize a merit-order-based approach to dispatch power. The merit-order-based approach allows the most economically efficient power to take the priority. Unlike other countries, China treats all the coal-fired power generators fairly. Regardless of high or low efficiency of power generation, the generators with similar size and capacity share the same generation quota. Thus, some certain amount of power is failed to be accommodated effectively. Similarly, wind power dispatch is encountering even more difficult situation. On the one hand, the wind power is intermittent and only serves as a back-up power. In Zeng et al. (2014)'s research, with Inner Mongolia as an example, they illustrate the prominent installed capacity of thermal power in year 2014 to be 31,072 MW, and among it the heating units account for 57.35%. In winter, the insufficient load regulation results in wind power abandoning to "give way" to the heating units. The same case also happens in other regions. The integration of wind power with other power sources always conflicts, and thus wind power is abandoned due to the random and intermittent characteristics.

1.5. Localization and Competitiveness of Wind Power Enterprises

1.5.1. Wind Turbine Manufacturers

During the past ten years, the development of domestic wind turbine enterprises became various in terms of firm nature. The industry localization trajectory is depicted by Fig.1.11 and Fig.1.12 In year 2006, among the top 20 wind turbine manufacturers in the Chinese market, only 4 of them are Chinese-owned enterprises, including Goldwind, Sinovel, Windey and DEC. In the year 2018, among the top 20 wind turbine manufacturers, 15 of them are Chinese-owned enterprises, namely Goldwind, Mingyang, Sinovel, Envision, DEC, XEMC, Haizhuang Windpower, Windey, China Creative Wind Energy, CRRC and SANY HEAG, ENERGIE, Jingcheng New Energy and Xuji. The Chinese-owned manufacturer Goldwind has ranked the first from 2006 to 2018, and the share of cumulative wind power installed capacity of Goldwind has kept a stable level which ranges from 20% to 25%. The share value of Sinovel was 17.75%, 22.4%, 18.8% in year 2008, 2010 and 2012, respectively, but dropped to 13.79% in 2014 and further dropped to 9.8% in year 2016. The Chinese-foreign owned manufactures United Power and Sewind accounted for around 15% of the capacity share from 2015 to 2018. The competition among various Chinese-owned manufacturers was fierce from year 2010 to 2018. Some of the enterprises appeared in the top manufacturers' list but gradually faded out, such as New Unite, Zhuzhou Csr Times, HEAG, Yinxing, CASC-Acciona, Xuji wind electricity, etc. This might be due to the enactment of two important policies in year 2009, one being the aforementioned distinguished FIT price of wind resource, another being the *Notice on Value-added Tax Policy of Wind Power Generation* stipulated by the Ministry of Finance, which provided favourable tax preferential incentives for enterprise income tax (EIT) and value-added tax (VAT). The *Notice* stipulated that for wind energy project in China, The VAT was deducted from 17% to 8.5% while the EIT was exempted during the first three years, and then deducted from 33% to 15% during the second three years. This tax deduction policy is extremely beneficial and attractive for the localization of domestic manufacturers. The change of wind turbine market become more vibrant and active and many enterprises are willing to produce wind turbines, leading to frequent market alternating and refreshing.

Figure 1.11 Top-ranking wind turbine manufacturers regarding the share of total installed capacity in 2006.

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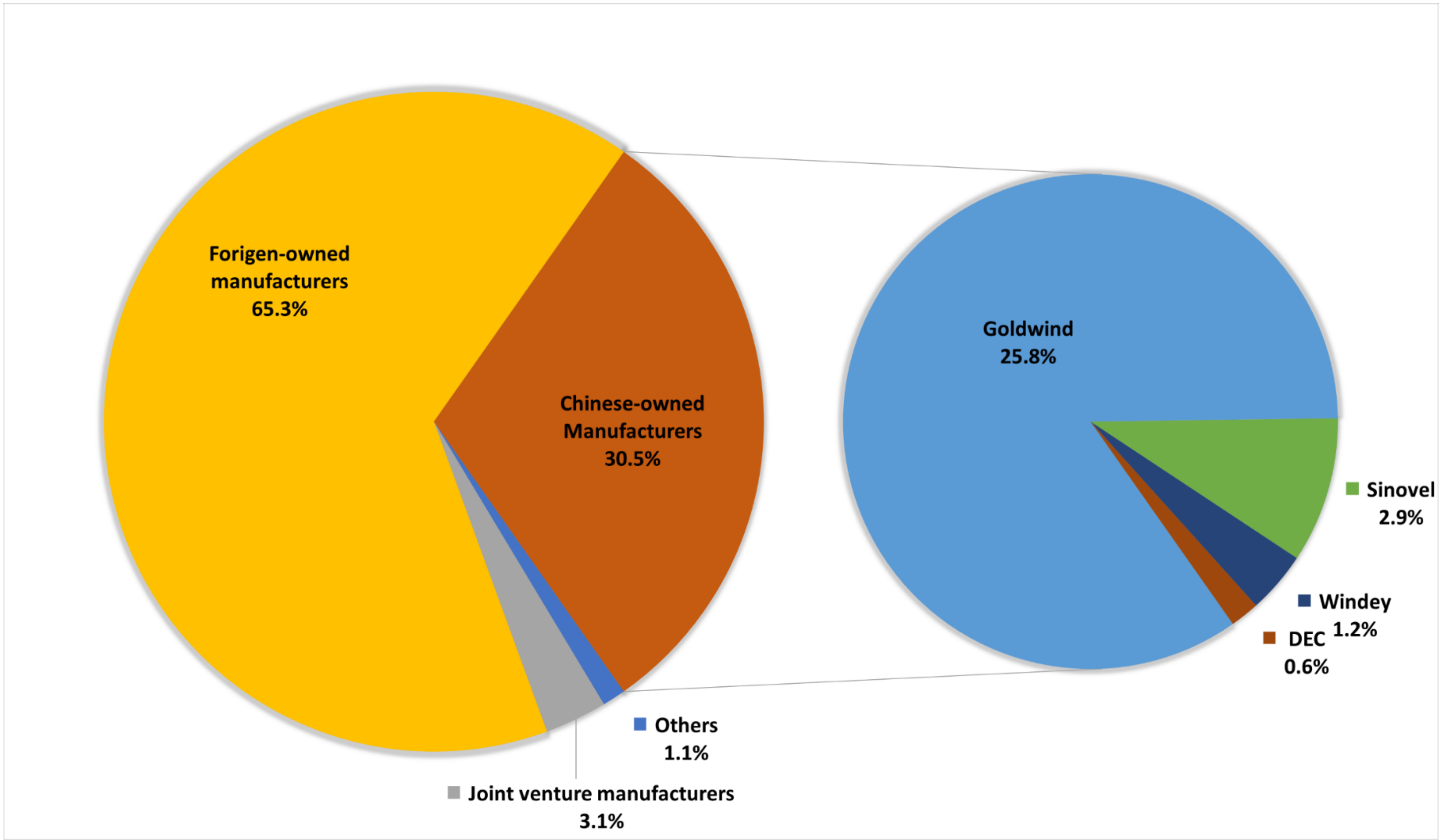
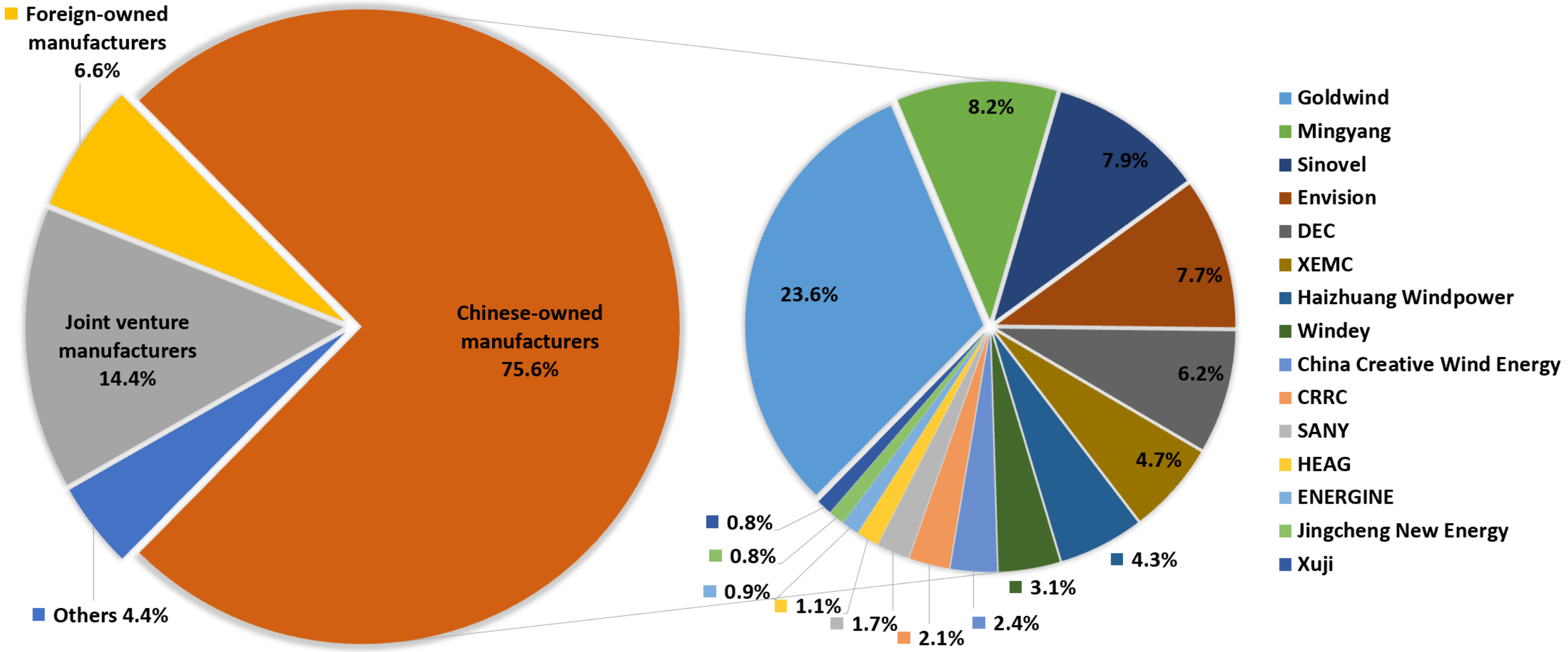


Figure 1.12 Top-ranking wind turbine manufacturers regarding the share of total installed capacity in 2018.



The total installed capacity of top Chinese-owned, joint venture, and foreign-owned manufacturers from 2006 to 2018 is shown in Fig.1.13, and the trend of structural change of firm nature is illustrated in Fig.1.14. The most prominent feature is the significant increase of wind installed capacity by Chinese-owned manufactures. In year 2006, the national total installed wind capacity was 2,589 MW and more than half was produced by foreign-owned manufacturers. The wind installed capacity by Chinese-owned manufactures increased abruptly between year 2008 and 2009 and achieved 31,649.98MW in 2010. From year 2006 to year 2018, the average annual increase rate of total installed capacity was around 51.8%, and the increase rate of total installed capacity by Chinese-owned manufactures was 64.9%, which directly promoted the development of wind energy in China. It is found that there is a trend of structure turnover from foreign-owned manufacturers to joint-venture and Chinese-owned manufacturers. In year 2006, the foreign-owned wind turbine manufacturers had dominated China's domestic wind energy market, with 65.33% share of the total installed capacity. However, in year 2008 and 2010, the share of foreign-owned enterprises sharply dropped from 35.56% to 17.5%. Afterwards, the share of foreign-owned enterprises kept dropping annually, and in year 2016 the share value was only 5.97%. For comparison, the share of Chinese-owned enterprises in terms of the total installed capacity increased abruptly from only 30.48% in year 2006 to 70.70% in 2010 and kept steady from year 2010 to year 2018 (share value of 75.5%). In addition, joint venture enterprises kept increasing steadily but sluggishly from 3.05% in year 2006, and for the first time exceeded foreign-owned enterprises with a share of 14.6% in year 2014, and finally reached 15.06% in year 2016.

Figure 1.13 The total installed capacity of top wind turbine manufacturers regarding firm nature.

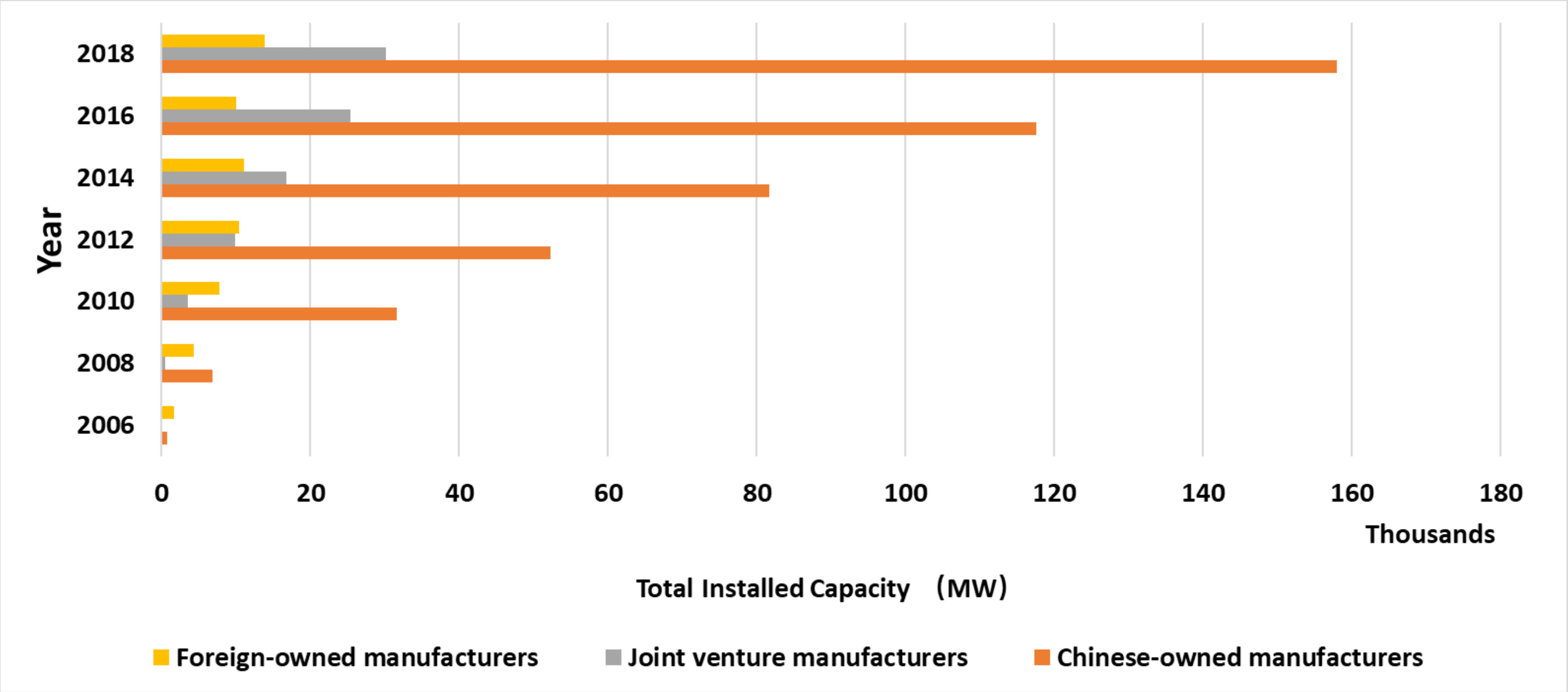


Figure 1.14 Firm nature change of wind turbine manufacturers in China's domestic market from 2006 to 2018.

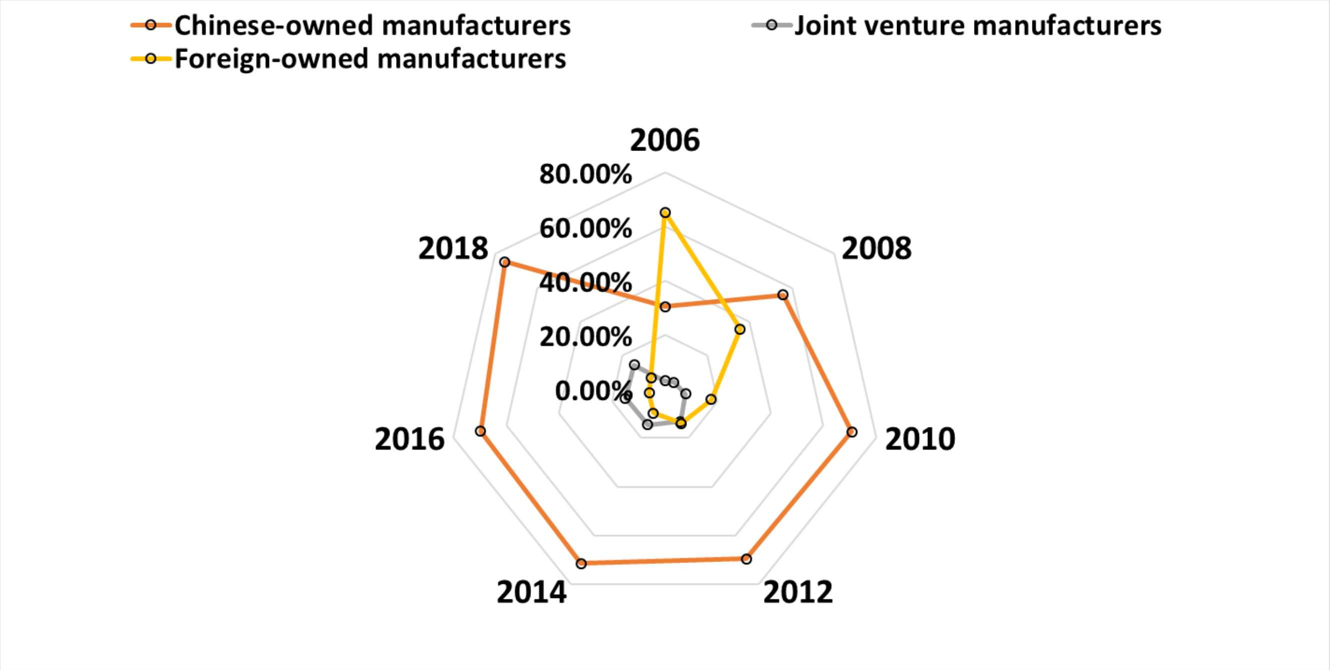
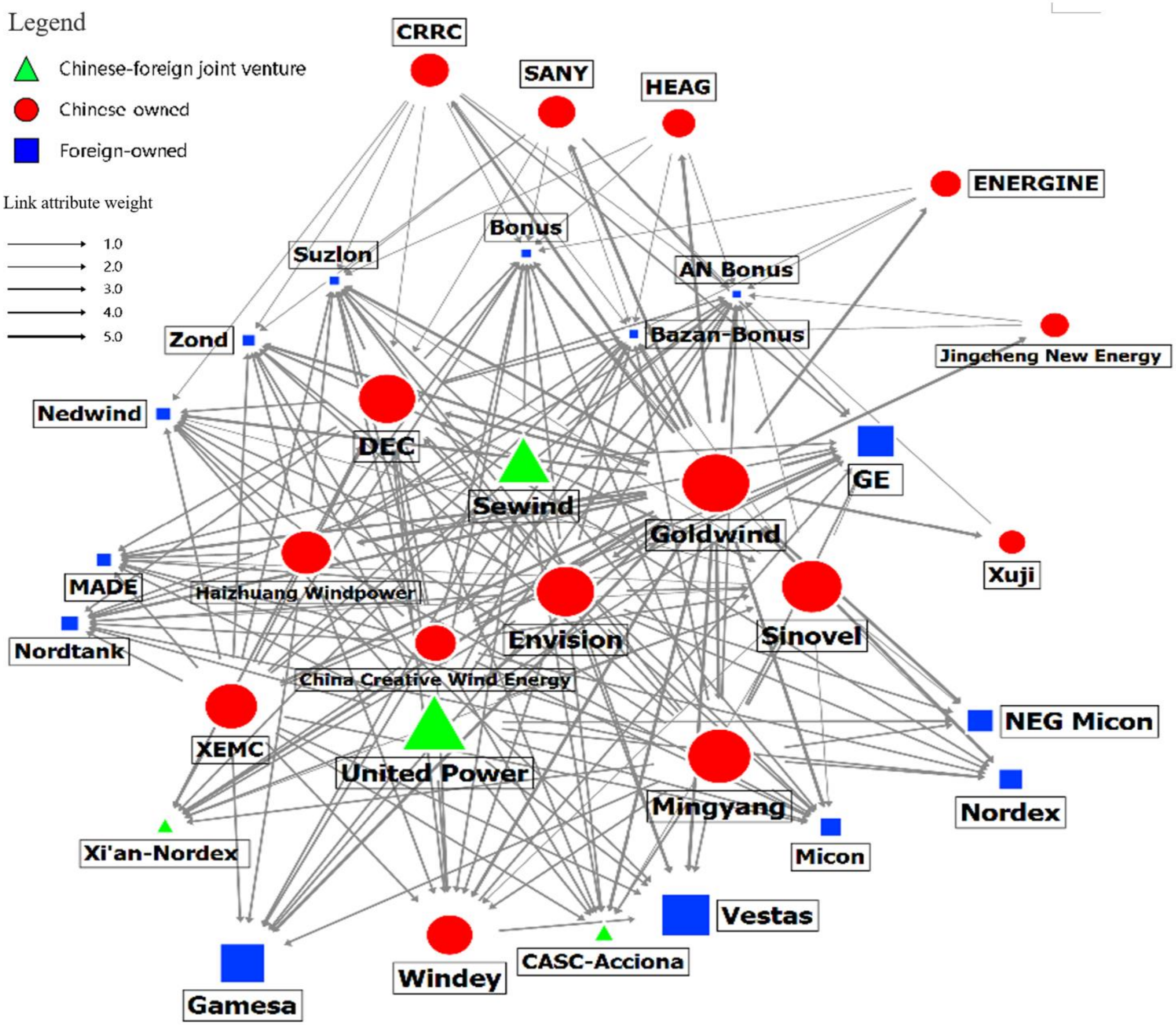


Fig.1.15 demonstrates the competitive relationship among onshore wind turbine manufacturers from 2006 to 2018 by SNA methodology. As Fig. shows, a significant change of onshore wind turbine manufacturers is the change of firm nature. At the beginning stage of wind power development, the foreign-owned manufacturers are dominating the Chinese manufacture market. After a series of tax reduction policies implemented by the government, the Chinese-owned manufacturers as well as two Chinese-foreign joint venture manufacturers (Sewind and United Power) are protected from taxation and become more competitive agsinst foreign-owned manufacturers. Consequently, the foreign-owned manufacturers are eliminated by the market as they are marginalized by a lot of Chinese-owned manufacturers which are at the central in the figure

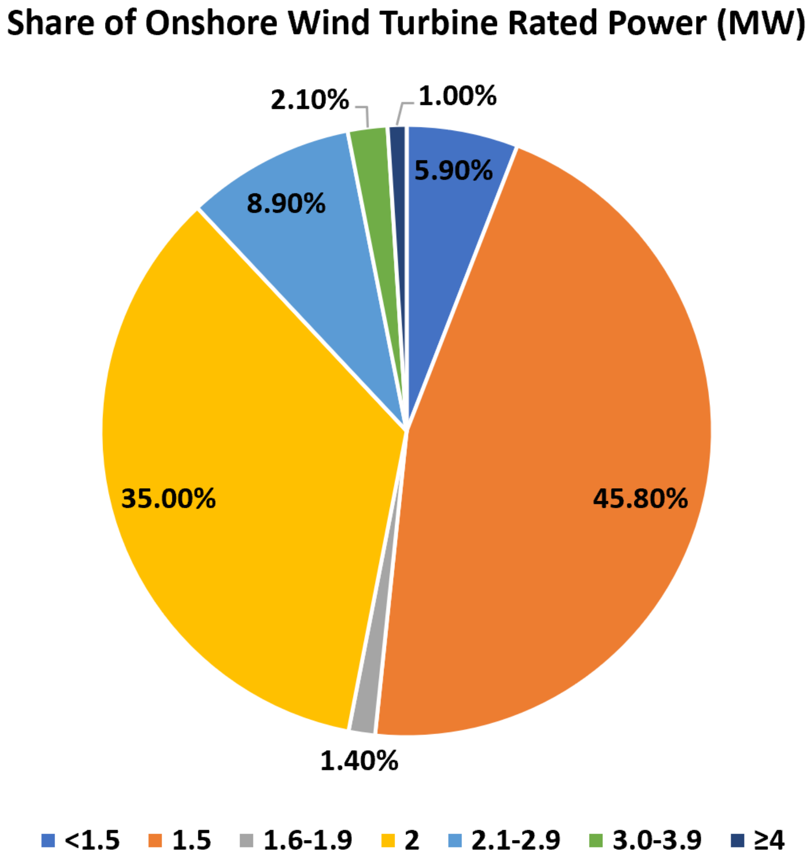
Figure 1.15 SNA of competitive relationship among onshore wind turbine manufacturers from 2006 to 2018.



3.

In addition, the share of manufacturers' onshore wind power plant rate power is illustrated in Fig.1.16 More than 90% of the wind turbines are large-sized wind turbines (≥ 1.5 MW). Nearly half of the wind turbines are rated 1.5 MW while 35% of the wind turbines are rated 2 MW. Only 5.9% of the wind turbines are small-sized or medium-sized that are rated less than 1.5 MW. The rapid commercialization of large-sized wind turbine production is benefited from a series of industry policies, such as the importation of main conmponents of large-sized wind turbines, the revitalization on equipment manufacturing, and the standardization of the technology (Yuan, Na, Xu, & Zhao, 2015). The mass production of large-sized wind turbines by the leading Chinese-owned manufacturers enables their expansion from regions in Category I, II and III to Category IV. Therefore, their ability of controlling the market is rather high (Zhao, Ling and Zillante 2012).

Figure 1.16 Situation on onshore wind turbine rated power



1.5.2. Wind Power Developers

As shown in Fig.1.17, the top-ranking wind power developers are all state-owned enterprises (SOEs). The ranking of wind power installed capacity market share is stable over years. As the so-called "state capitalist" in the electricity market by (M. Zhu, Qi, Belis, Lu, & Kerremans, 2019), "Big Five" and "Small Four" enterprises[2] account for 61.7% of the market share. Among which CHN Energy, Huaneng, Datang, Huadian, GD Power and CGN are inevitably dominating the wind power investment market. China Shenhua Corporation has announced its jointly restructuring to China Guodian Corporation in 2017, so the installed capacity of Shenhua is removed from the figure. Due to the concession of Shenhua, China Three Gorges Corporation has taken part in the ranking list, as well as China Resource, Tianrun Group and Power Construction Corporation of China, has shown their competitiveness among all the developers. Besides, it is found that the cumulative installed wind power capacity by other enterprises was increased from 25% of market share in 2013 to 30% in 2018, which includes a large amount of non-SOEs. This situation indicates that the wind power investment market is regulated by the Chinese government so that the SOEs are more favourable, but at the same time, the non-SOEs are increasingly inclusive by the market.

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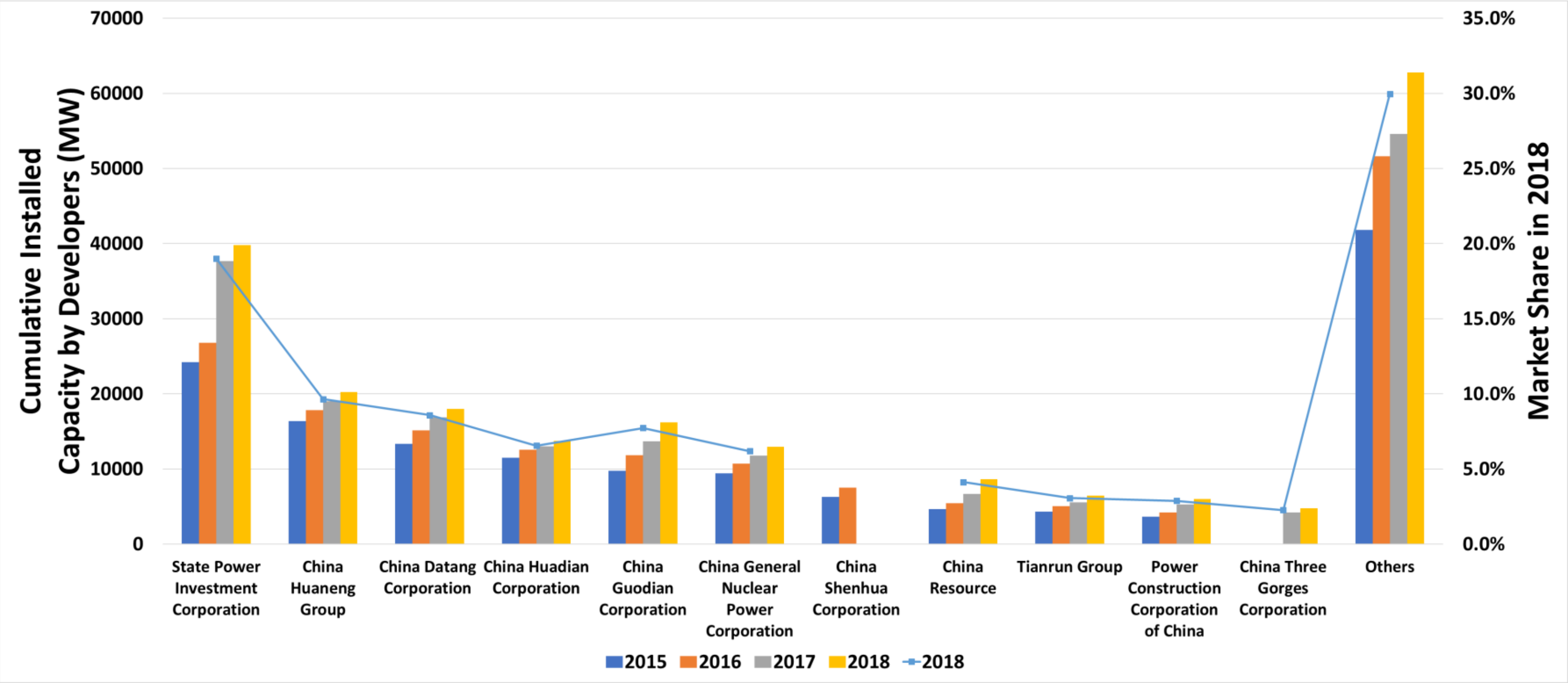
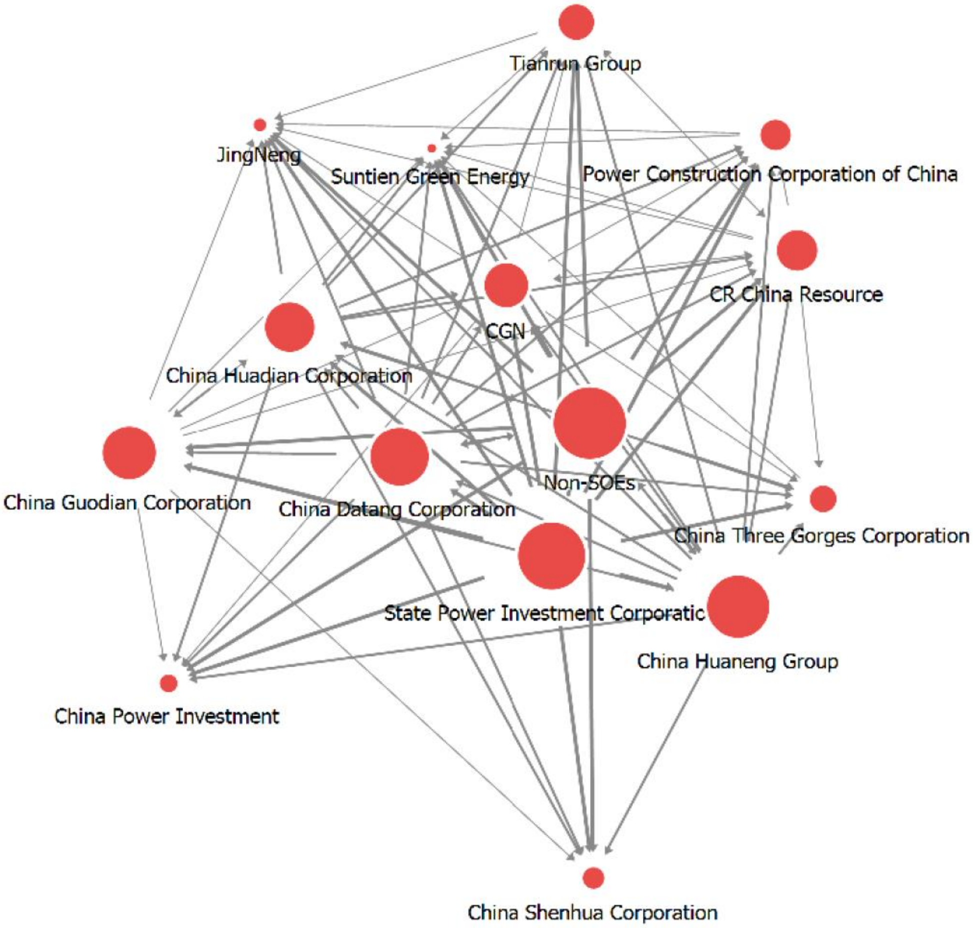
[2] "Big Five": China Huaneng Group, China Datang Corporation, China Huadian Corporation, China Guodian Corporation, State Power Investment Corporation.
"Small Four": China Resource, State Development and Investment Corporation, China General Nuclear Power Generation (CGN), Guohua Electric Power Company.

Figure 1.17 Top-ranking wind power developers from 2015 to 2018.



The SNA result of the competitive relationship among wind power developers from 2011 to 2018 is presented in Fig.1.18. Jingneng and Suntien Green Energy, which has been ranked the top ten wind power developers in 2013 are eliminated from the list in 2018. The competitiveness of "Big Five" and "Small Four "is inevitably stable, but Tianrun Group and China Three Gorges Corporation also show great potential of developing wind power.

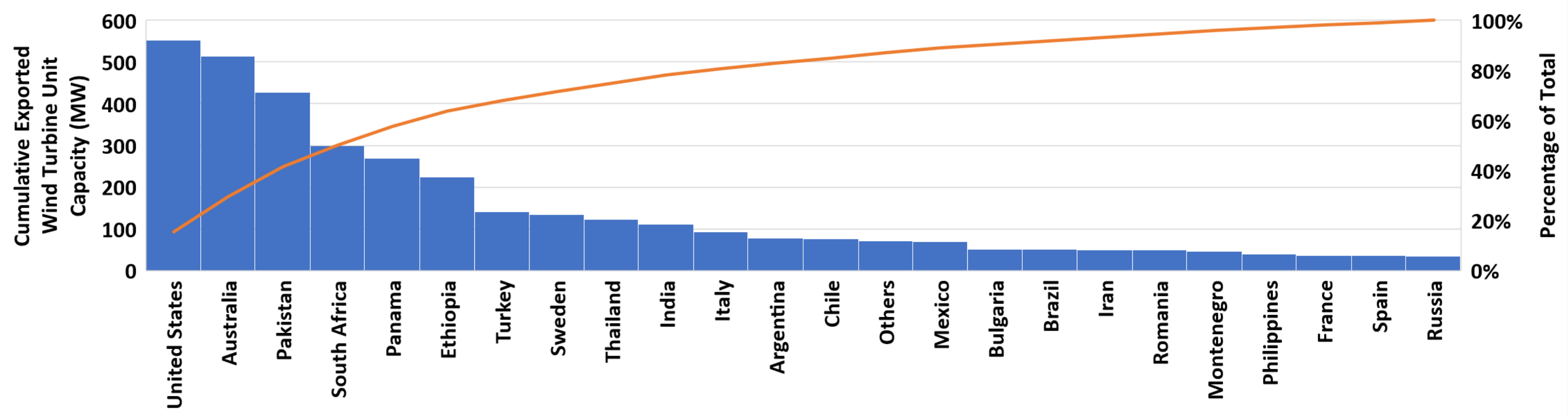
Figure 1.18 SNA of competitive relationship among wind power developers from 2011 to 2018.



1.5.3. Exportation and Internationalization

Fig.1.19 illustrates the main exportation countries of wind turbine units from Chinese manufacturers. The United States and Australia are two largest export destinations for wind turbine manufacturers, which account for 30% of the total exported capacity. Besides, Pakistan, South Africa, Panama and Ethiopia account for around 35% of the exported capacity. It is found that the top-ranking exportation countries are mainly located far from China, such as countries in North America, South America and Europe. Whereas there are only a few adjacent countries to China which are export destinations. It is also found that the internationalization of Chinese wind turbine manufacturers considers both developed countries and developing countries, which is consistent with Zhang et al. (2015)'s conclusion. The amount of wind turbine unit exportation drastically increases from 45 MW in 2009 to 3581 MW in 2018. Apart from the reason that the competition of domestic wind turbine manufacturers is intense and the reason that wind power curtailment problem has weakened some manufacturers' confidence in domestic market, the supporting policies enacted by the government play a crucial rule. In 2009, the State Council (SC) issued the *Notice on Curbing the Overcapacity and Redundant Construction of Several Industries and Promoting the Healthy Development of Industries*, which encourages to promote the internationalization of wind power industry (SC, 2009). Soon in 2011, the government's ministerial departments co-issued the *Opinions for Promoting the Internationalization Development of Strategic Emerging Industries*, which has boosted the fast exportation and internationalization of wind turbine manufacturers.

Figure 1.19 Main exportation countries of wind turbine units from Chinese manufacturers in 2018.



1.6. Chapter Conclusion

This thesis has provided a comprehensive overview on the wind power development from the commencement of REL to the end of 2018. Data collected from official websites of government (such as State Council, National Development and Reform Commission and National Energy Association, etc), research institutions (such as Chinese Wind Energy Association), official documentation (such as Statistical Yearbook China), journal articles and the official websites or reports of wind power enterprises are used to illustrate the status quo of onshore and offshore wind power development. Installed capacity, gird-connected wind power, wind farm capacity factor, abandoned wind power and wind curtailment rate are introduced by means of explaining the implementation of series of supporting policies. The top-ranking manufacturers and developers in domestic wind power market are presented in the overview, while the change trend of firm nature and competition relationship among the enterprises are illustrated. Besides, SNA has been employed to demonstrate the competitiveness of wind power enterprises over the past years, which shows the policy effectiveness on localizing the wind power industry. All in all, this chapter concludes that the effectiveness of wind power policies enacted is high, and they play a vital role in Chinese wind power market. In addition, it is expected that in the near future, the Chinese wind power market will be regulated also under a policy-oriented mechanism.

CHAPTER TWO

The Evaluation of Current Wind Power Feed-in Tariff Policy

2.1. Introduction

2.1.1. Policy Mechanism of Current Wind Power Feed-in Tariff Policy

The wind power development in China has been witnessed a rapid and stable increase over the past decades, the main reason is attributed to the enactment of various price-policies and non-price policies. The non-price policies include the target-based regulatory policies, mandatory access to grid policies, and cost sharing arrangement, etc. The price policies include a series of subsidizing policies, funding and tax preferential policies to support on investors, enterprises and R&D development, etc. Among which the Feed-in-Tariff (FIT) policy is evaluated as the most influential policy to stimulate the wind power development in China by numerous researches (Kang, Yuan, Hu, & Xu, 2012; Liao, 2016; Sahu, 2018a; Schuman & Lin, 2012; Shen & Luo, 2015a; S. Zhang, Andrews-Speed, & Zhao, 2013; S. Zhang, Zhao, Andrews-Speed, & He, 2013). However, these studies are based on content analysis and the effectiveness of wind policies are analysed from a descriptive and informative way. Empirical analysis within this study field is rather scarce under the Chinese context. There is only one conducted by Zhao et al. (X. Zhao et al., 2016). In their study, a penal data regression model was employed to evaluate the effectiveness of price policies and non-price policies on wind power development. No related empirical studies could be found on explicitly only analysing the FIT policy for the sake of its effectiveness, which is the research gap identified for this thesis.

Currently, the FIT wind power policy design in China is basically determined by wind resource distribution (Hu, Wang, Byrne, & Kurdgelashvili, 2013). Annual average effective wind energy density (ρ) and annual cumulative hours (H) of wind speed of 3-20 m/s are two indicators for wind resource classification (X. Zhao et al., 2016). The National Development and Reform Commission (NDRC) has stipulated four wind resource areas within the nation (namely Category I, II, III, IV), and a higher FIT is provided to relatively poor wind resource areas while a lower FIT is provided to relatively rich wind resource areas (Appendix. A). Promoting the development of wind energy in poor wind resource areas are extremely important in China, because the centre-load of electricity consumption areas are clustered mainly in Category IV, thus the adoption of wind power in these areas could positively relieve the burden from the supply side.

In China, the 31 provinces, autonomous regions and municipalities are divided into 6 regional power grids (Ying Li, Lukszo, & Weijnen, 2016). China has two state-owned grid companies, namely State Grid Corporation of China (SGCC) and China Southern Power Grid Corporation (CSG), respectively. SGCC accounts for 26 provinces/autonomous regions/municipalities including North China Grid (Beijing, Tianjin, Hebei, Shanxi, West Inner Mongolia and Shandong), Northeast China Grid (East Inner Mongolia, Liaoning, Jilin and Heilongjiang), Central China Grid (Henan, Hubei, Hunan, Jiangxi, Sichuan and Chongqing), East China Grid (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian) and Northwest China Grid (Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Tibet), CSG covers the remaining 5 provinces in South China Grid (Guangdong, Guangxi, Yunnan, Hainan and Guizhou).

However, although the FIT policy has played a critical role to stimulate the rocketing development of wind power generation over the past ten years, the capacity factor of wind farms is quite low since the wind curtailment phenomenon in China is rather severe, and a large amount of wind power could not be accommodated to the demand side (Bird et al., 2016; Fan, Wang, Shi, & Li, 2015; Luo, Li, Tang, & Wei, 2016b). Under this circumstances, Xia and Song (2017) indicate that the FIT policies should be reformed. In Xia and Song's research, a partial adjustment model is applied to analyse the determinants of wind power installed capacity. Their conclusions are based on investors' perspectives, they found that the power demand factor does not significantly affect the location choice of wind farms by investors, but the governmental subsidies have large effect on such a choice. However, Zhao et al. (2016) have applied variable intercept model to evaluate the effectiveness of China's wind power policy, and concluded that power demand has significant effect on the increase of wind power capacity. What's more, they pointed out that the current wind policies have hindered the further development of wind power and more flexible wind policies should be implemented by government based on adjusting on-grid wind power price, renewable energy trading price across regions and supplementary service price related to wind power generation. Sahu (2018) has reviewed the wind energy developments and policies in China and indicates that wind curtailment problem is not taken account into the design of FIT policy by policy makers, because it would impede target achievement of wind power capacity, but keeping ignorant on this problem would continuously aggravate the wind curtailment problem. It is undoubtable that the reasons for severe wind curtailment problem are miscellaneous, such as technical aspect, institutional aspect and R&D aspect (L. Li, Ren, Yang, Zhang, & Chen, 2018a; Q. Wang, 2010; Z. Wang, Qin, & Lewis, 2012b), but the improvement of these aspects requires constantly policy support and long-term observation, thus the policy reform is considered a straightforward, sophisticated and vigorous aspect to alter all the aforementioned aspects. It is clear to find that all stakeholder involved in the wind power industry are concerning about their own interests. The grid companies attribute sever wind curtailment problem to state grid of not constructing sufficient transmission lines, but the state grid is also in a dilemma because obtaining approval on transmission line construction from the government is complicated and sluggish (L. Li et al., 2018a). Obviously, the current FIT policy could not satisfy various considerations, and should be reformed by actions to be adapted by the changing environment of economy, energy and politics in China.

Therefore, this thesis aims to investigate the effectiveness of current FIT policy on stimulating the cumulative installed wind capacity and annually added wind capacity from Year 2005 to Year 2016, and to identify the influential determinants on wind energy development except from FIT and wind resource potential. Besides, considering that the six regional power grids and the four categories of wind resource in FIT policy demonstrate inconsistent classification of administrative areas, this thesis is curious about the effectiveness of FIT policy on different power grids. To achieve the specific aims, this thesis therefore includes the following objectives: 1) examine whether the wind farm location is crucial to the development of wind energy and whether the rich wind resource regions are more favourable and advantageous for consideration; 2) verify that distinguishing the FIT prices after Year 2009 are effective on improving the wind energy development in poor wind resource areas; 3) identify the influential determinants in improving wind energy development by adding control variables in the regression model. It should be noted that these objectives are conducted both at the national level and at the regional level, and the dependent variables are cumulative wind installed capacity as well as annually added wind capacity. To achieve objective 1) and 2), two hypothesises are created as follows:

Hypothesis a): Wind capacity increases if wind farms are constructed in regions of rich wind resource

Description of Hypothesis a): Although the FIT price in Category I, II and III are relatively lower than that of Category IV, but since the wind resource are abundant, these regions are still attractive and thus the wind energy development is rather significant;

Hypothesis b): Wind capacity increases if wind farms are constructed in regions of higher FIT prices.

Description of Hypothesis b): Although the wind resource in Category IV is not as abundant as in Category I, II and III, but since the FIT price is relatively higher in Category IV than others, so it is favourable to investors, thus, the development of wind energy in Category IV is significant.

2.1.2. A Summary of Wind Development Features in China

The aforementioned analysis reveals that the wind power curtailment problem in China is severe. The wind farm capacity factor in China is also lower than those in other countries. To promote the capacity factor of wind farm, the wind power connected to the grid should be further improved because the rated wind farm capacity and the annual hours remained unchanged. Therefore, one of the solutions to solve the problem of low capacity factor is to solve the problem of grid connection management and is equivalent to solving the problem of wind power curtailment.

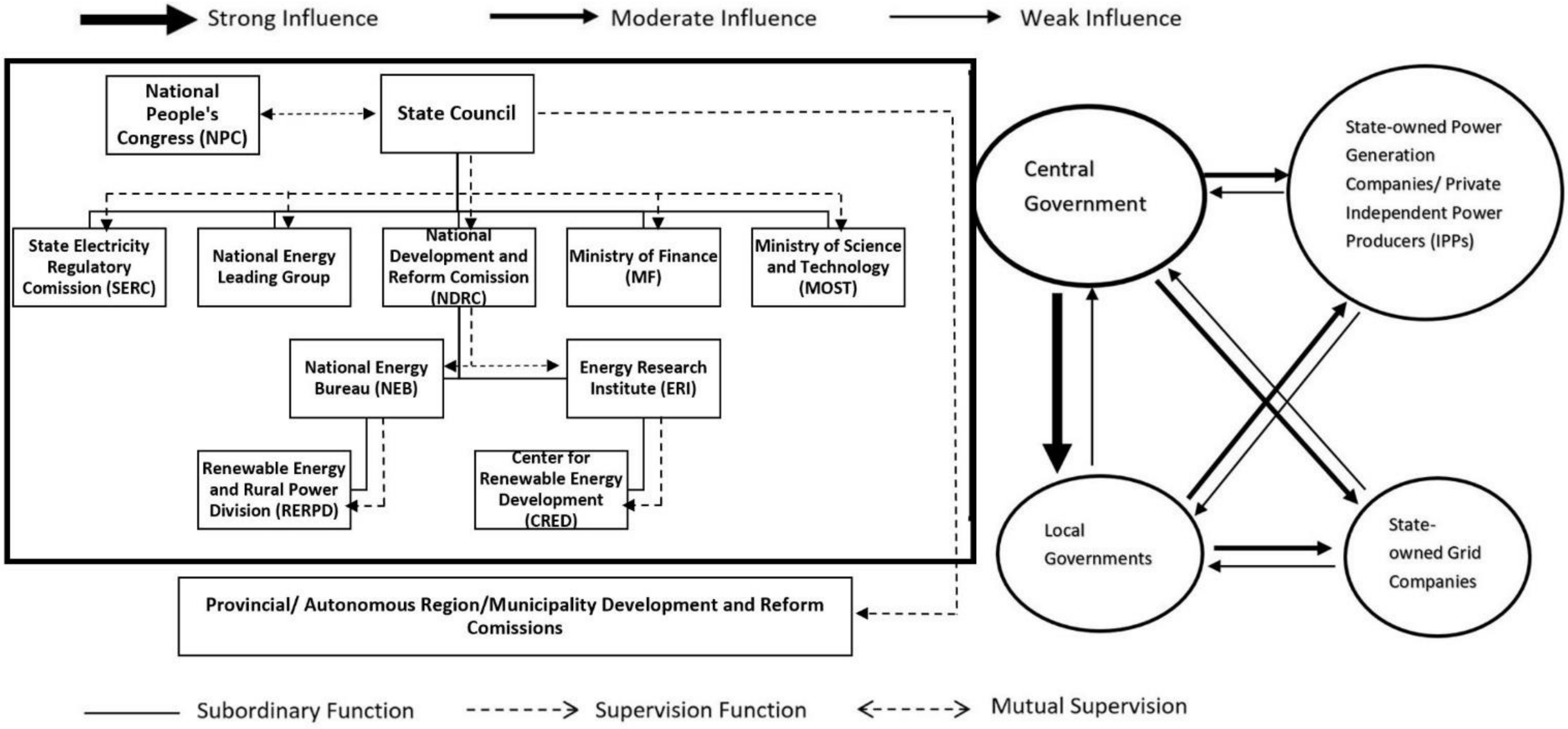
Three features are identified to depict the trajectory of grid-connected wind power and wind farm capacity factor. First, no obvious relationship is found between the amount of grid-connected wind power and the value of capacity factor. Fujian, Shanghai and Hainan indicate higher capacity factor, but at the same time the amount of grid-connected wind power is very low. By contrast, Xinjiang, Hebei, Gansu, Shandong and Shanxi have larger amount of grid-connected wind power, but the values of capacity factor are fluctuated based on the average value and barely prominent. Second, the change of wind farm capacity factor in each region followed similar trend in the past four years. Third, the value of capacity factor is not closely related to the installed capacity in different grids. North and Northwest China grids have most of installed wind capacity, but their capacity factors are very different. East China grid has the highest capacity factor of 18.9%, followed by the second highest the North China grid of 17.2%. Northwest has the lowest capacity factor of 11.1%.

Three features are summarized to describe the wind power curtailment problem. First, it primarily happens in North grid, Northeast grid and Northwest grid, where the electricity demand is not as heavy as the load centre. It is also observed that the more wind turbines are installed, the severer the wind power curtailment takes place. Second, the change of the wind power curtailment rate follows a parabolic-shaped curve in the recorded years. Both the national average wind power curtailment rate and most of the listed provincial-based wind power curtailment rate dropped from year 2013 to year 2014, and then rebounded in year 2015 and year 2016. Third, although the proportion of wind installed capacity in Area I, II and III to the national level is decreasing annually, the quantitative amount of these areas is still prominent, and the wind curtailment amount is closely related to wind installed capacity.

2.1.3. Central-Local Policy System in China

The policy-making structure in China is highly centralized, strictly top-down ruled and strongly government controlled against state-owned enterprises. The bureaucratic structure of decision-making system regarding the renewable energy policy is demonstrated in Fig. 2.1. National People's Congress (NPC) is the supreme legislative organization of state power in China. It enacts basic laws legislations of the state and elects the leading personnel of the highest state organs of China, including the State Council (SC). The SC is the highest administrative organization of China. It directly supervises the various subordinate bodies in the renewable energy decision-making system, including the State Electricity Regulatory Commission (SERC), the NDRC, the MF and the Ministry of Science and Technology (MOST). The SERC supervises the electricity system of the state. The National Energy Leading Group and the NDRC are two major institutes under SC to formulate renewable energy price measures. The MF is the national executive agency which administers macroeconomic policies and the national annual budget and at the same time handles fiscal policy, economic regulations and government expenditure for the state (State Council, 2014). The MOST takes the lead in drawing up science and technology development plans and policies, drafting related laws, regulations and department rules, and guaranteeing the implementation (Ministry of Science and Technology of People's Republic of China, 2014).

Figure 2.1 Bureaucratic Structure of Decision-making System in China regarding the Renewable Energy Policy. Source: official website of National People's Congress, official website of the State Council and Mah and Hills (2008).



The Provincial/Autonomous regions/Municipality Development and Reform Commissions are supervised by the SC and responsible to the NDRC. The "controlled delegation" feature is rather salient in the Chinese context and the Central Government has strong influence on the behaviour of local governments. The local governments have the obligation to collect information which belongs to their locality and are responsible to report to the NDRC. Besides, the Central Government entitles local governments independent rights to approve wind farm projects with capacity below 50 MW. However, large projects (above 50 MW) require approval from the central government (Y. Liu & Kokko, 2010).

2.2. Drawbacks of China's Wind Energy Policy Mechanism

Extensive studies have analysed the causes of low capacity factor and severe wind power curtailment in China. Their main conclusions are summarized in Table 2.4. The Research and Development (R&D) institutions, manufacturers, power generation enterprises, grid companies, local government and central government are main parties to be engaged in the wind energy industry in China. The central government plays the most crucial role of policy-making and affects the actors' behaviours in the wind power supply chain.

2.2.1. Policy Maker – Central Government

2.2.1.1. Inconsistency of Wind Power Generation and Grid Power Planning

The Chinese government is pursuing a capacity-based target rather than a generation-based target. However, inconsistent phase of wind farm construction and grid power planning has aggravated the wind curtailment problem. The Chinese government put forward the grand vision of establishing a project of "Wind Power Three Gorges" in year 2016 and planned to achieve the wind power capacity of 130 million kW by 2020. However, without comprehensive power grid planning, the accommodated wind power is far less than the constructed wind power. The central government failed to coordinate the national power generation and transmission, but only met a magnificent data of installed capacity (Luo et al., 2016; Si et al., 2011; Wang et al., 2012; Zeng et al., 2014). Another issue is also related to insufficient grid power planning, which is lacking on-time demand response monitoring. In China, the peak load regulation and management is immature due to inadequate consideration of power source accommodation and planning. In practice, the peak load power source construction is lagged behind, and the increased wind power output is restricted by the power system due to insufficient capability of on-time peak time demand response. Thus, the wind power cannot be accommodated.

The policy design of differentiating central and local government rights for approving wind power projects with "50 MW" led to an obvious phenomenon of extremely large number of "49.5 MW" projects (Y. . Zhang, 2009). In order to simplify the declaration process, some power generation enterprises divided large-scale wind power projects into pieces of small-scale projects under "50 MW" each (most frequently "49.5 MW"). Once the sub-projects are approved by the local government, they start to construct the wind farms separately with names as "wind farm stage I", "wind farm stage II", etc. Consequently, the fragmented multi-stage wind farm construction causes the grid connection to be done by stages, and the wind power connection to grid is completed in separated parts of a region, which in turn leads to the mismatch between wind power generation and grid power planning. Therefore, institutional defects were found regarding the central-local government to approve wind power project by a capacity of 50 MW (Luo, Zhi, & Zhang, 2012).

2.2.1.2. Low Offshore Wind Power FIT Price and Cost Sharing Incentive

Apart from the inconsistency of grid power planning and wind power generation , the offshore wind power FIT is found too low to attract investment in China (Z.-X. He et al., 2016), as shown in section 6. Besides, in order to release the cost burden of renewable power transmission, the cost is shared by all the consumers with the price of 0.01 RMB/kWh/50km, 0.02 RMB/kWh/50-100 km, 0.03 RMB/kWh/100 km[3]. However, the current grid dispatch incentive of renewable energy sources is found to be too low (Luo et al., 2016). The suggested reasonable incentive based on actual expenses of power grid enterprises could be 0.012 RMB/kWh/25km, 0.033 RMB/kWh/75 km, and 0.054 RMB/kWh/120 km[4] (Y. . Zhang, 2009).

2.2.1.3. Low Priority of Energy Management Authorities

In addition, a very unique phenomenon in China is the low priority of energy management authorities, such as the NEB and the ERI. Although they can enact wind energy policies, the actual power is controlled by the administrative and fiscal authorities, such as the NRDC. Thus, the implementation and coordination rights of renewable energy development are mastered by governmental authorities without much consideration of energy planning (Shen and Luo, 2015). By contrast, in the United States, the formulation and implementation of energy policies are conducted by both federal and non-governmental stakeholders (Energy policy in the United States). For example, regarding the federal policy stakeholders, the United States Department of Energy (DOE) and the Energy Information Administrative (EIA) shoulder independent responsibilities. The former plays a crucial role in the energy policy formulation while the latter is responsible for collecting, assisting, and publishing statistical information and analyses to support DOE initiatives. Besides governmental agencies, non-governmental stakeholders also exert various extent of influence on energy policies. Different from China's administrative mechanism, the aviation industry, the

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[3] 0.01 RMB, 0.02 RMB and 0.03 RMB are equivalent to 0.0015 USD, 0.0030 USD and 0.0044 USD, respectively.

[4] 0.012 RMB, 0.033 RMB and 0.054 RMB are equivalent to 0.0018 USD, 0.0049 USD and 0.0080 USD, respectively.

automotive industry, the manufacturing industry, and the finance industry also hold stakes in U.S. and international energy policy.

Table 2.1 Reasons for low capacity factor and severe wind power curtailment by researches

Study	Central Government	Local Government	Grid Companies	Power Generation Enterprises	Manufacturers	R&D Parties
Shen and Luo (2015)	-Should encourage technology innovation rather than enterprises enter the market	-" Locality treat, centre billed", wind projects under 50MW are approved by local government but the expenses are shared nationwide			-Flocked to the downstream of supply chain with high profit and low technology	-Need great quantity of capital, but tight monetary policy aimed at curbing inflation makes it difficult for bank loan
Luo et al., (2016)	-Inconsistency between the wind power development and the overall grid planning -low grid dispatch price of renewable energy source.		-Lack of on-time demand response monitoring			- Lack of motivation for researches on cutting-edge wind power technology
Wang (2010)	-The right holders are economic and administrative resources authorities rather than the departments that are involved		-Monopoly of China's electricity industry, it is dominated by the state grid, so lack of technological information support			

	in wind energy industry					
Li et al. (2018)				-Use large size of turbine may aggravate the grid connection difficulties	-Unqualified wind turbine lead to more accidents -Processing technology in China is immature, thus some important parts of wind turbine cannot be manufactured locally	
Z.-X. He et al. (2016)	-Low FIT price for offshore wind power -Insufficient related policy support		-offshore wind power grid integration result in unstable and unsafe problem to the national power grids			
(Si et al., 2011; Z. Wang et al., 2012a)	-Lack of grid connection planning				-Duplication and technological homogeneity of wind-power equipment	

(Zeng et al., 2014)	-Uncoordinated wind power generation and grid power planning resulted in problematic transmission channel construction -Weak in grid construction, and high voltage transmission line construction is rather low		-Wind power grid integration is lagged behind, and peak load regulation is insufficient			
(Luo et al., 2012)	-Institutional defects -lack of a reasonable, efficient and uniform power supervision system	-Contradictions among responsibilities, rights and interests with grid companies	-No strict grid connection specifications			-Insufficient R&D fund in wind energy resource evaluation systems and national public platforms
Z. He et al. (2016)	-Low FIT price for offshore wind power -Relative subsidy policy is not clear	-Over-intervention by local governments			- Fierce competition and threats for small- and medium- sized manufacturers to enter the market	

2.2.2. The Ambiguous Position of Local Government

Coordination between central and local policies is hindered by excessive centralization. Local governments have to obey the command-and-control decision making system to push the development of wind power in locality. As a result, over-intervention by the local government happens all the time. Take the Jiangsu coastal wind-power industry cluster as an example, the over-intervention by Jiangsu government results in unhealthy wind power development in the local area. Under the vigorous government-led format of tax competition, performance evaluation and the quest for policy benefits (Z. He et al., 2016), the enterprises were directly affected by the government behaviour rather than driven by the market. Due to the achievement of the prominent development of wind power, the local government ignores that the wind power development should be a progressive way consisting of three phases: a learning period, a growing period and a maturing period. Besides, from the manufacturers' perspective, the rising degree of industry concentration makes the small-sized to medium-sized manufacturers more difficult to engage in the market due to fierce competition and threats. As aforementioned, in year 2016, the top 10 wind power manufacturers have accounted for 79% domestic market share of installed capacity, especially Golden Wind Technology accounts for 22.2%, taking the first place for consecutive years and being far ahead of the second place (9.8%). The leading position of several huge manufacturers are very stable over years, which makes the small-sized to medium-sized manufacturers difficult to survive.

Besides, the local governments' roles in grid planning are very ambiguous due to contradictions among responsibilities, rights and interests with grid companies. Although the grid power companies have handed over partial functions to relevant departments of local governments, some major functions such as technical improvements, power demand and supply are still dominated by the grid companies. Consequently, the misplacement and malpractice problems among local governments and grid companies become salient. The possible reason might be that the local governments are trying to enable grid companies to maintain some public powers, thus they could seek favourable but undeserved benefits through their hands, which affect the fairness of market transactions (Luo et al., 2012)

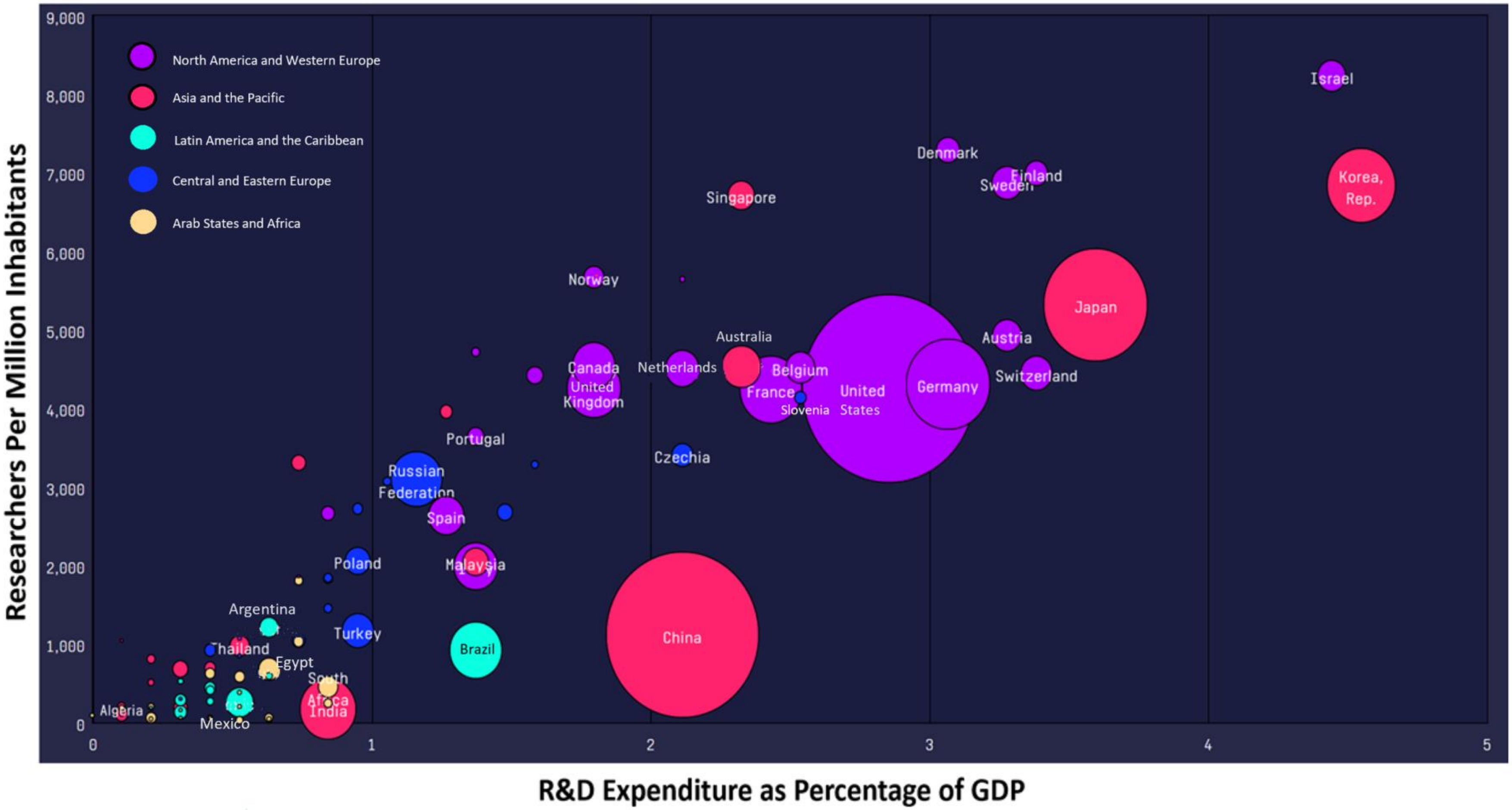
2.2.3. Other Actors and Parties

2.2.3.1. Insufficient R&D Personnel

Connecting the wind power to grid requires cutting-edge technologies such as demand response and forecasting, energy storage and specification standardization, and these require elaborate and comprehensive policy support. However, achieving a high-tech leading role in wind energy industry sounds difficult for China. First, the R&D personnel of wind energy technology in China is insufficient. As demonstrated by Fig. 2.2, it is found that generally the number of R&D researchers is proportional to the R&D expenditure of

GDP. In China, the R&D expenditure accounts for only about 2% of China' GDP and there are around 1096 researchers per million inhabitants. However, the number of researchers in China is significantly smaller than that of countries spending around 2% of GDP on R&D, such as Czechia (3400 researchers per million inhabitants), the United Kingdom (4254), Netherlands (4513), Australia (4539), Canada (4552), Norway (5687) and Singapore (6729). Specifically, most technicians involved in wind energy industries are engaged in other fields of industries, and they do not possess the professional knowledge of wind energy. As a result, the core technologies regarding wind equipment manufacturing, especially processing technologies, are not fully mastered by Chinese enterprises. Second, the Central government has not clearly defined the responsible parties for developing such technologies, and the relevant subsidy policies for stimulating R&D in wind technology are ineffective and insufficient. Thus, the grid power companies may have excuses to refuse the supervision from the Central government (Luo et al., 2016a). Third, it takes time to do R&D and to fully transfer the research results to applications. Therefore, Chinese enterprises are not willing to spend too much time on R&D and knowledge transfer, whereas they prefer to directly purchase mature technology from other countries. Therefore, the speed of wind power production in China is in the forefront of the world in spite of the relatively low level of R&D (Shen and Luo, 2015).

Figure 2.2 Proportion of R&D expenditure to GDP and research personnel by country in the world (UIS, 2019)[5].



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[5] The size of circles indicates the amount of R&D expenditure in Purchasing Power Parity (PPP) dollar.

2.2.3.2. Difficulties in Integrating Wind Power with Coal-fired Power

China's power dispatch follows a coal-fired power dominated approach and capacity-based pattern. The quota of coal-fired power generators is equally assigned according to scheduled generation capacity by the local government (Wei et al., 2018; Yin et al., 2017a). For example, a 400 MW unit is equivalent to two 200 MW units. In most of the other countries, the governments utilize a merit-order-based approach to dispatch power. The merit-order-based approach allows the most economically efficient power to take the priority. Unlike other countries, China treats all the coal-fired power generators fairly. Regardless of high or low efficiency of power generation, the generators with similar size and capacity share the same generation quota. Thus, some certain amount of power is failed to be accommodated effectively. Similarly, wind power dispatch is encountering even more difficult situation. On the one hand, the wind power is intermittent and only serves as a back-up power. In Zeng et al. (2014)'s research, with Inner Mongolia as an example, they illustrate that the prominent installed capacity of thermal power in year 2014 is 31,072 MW, and among it the heating units account for 57.35%. In winter, the insufficient load regulation results in wind power abandoning to "give way" to the heating units. The same situation also happens in other regions. The integration of wind power with other power sources always conflicts, and thus wind power is abandoned due to the fluctuating and intermittent characteristics. On the other hand, the lagged construction of power transmission lines has also impeded the trans-regional power utilization, which will be discussed in the next section.

2.2.3.3. Lagged Construction of Transmission Lines

To maximize the utilization of wind power generated in areas with rich wind resource, the wind power should be transmitted to areas with high electricity consumption such as Southeast grid and South China grid. This requires long distance delivery channel and ultra-high voltage (UHV)[6] construction. Wind power and thermal power UHV transmission lines are demonstrated in Fig. 2.3. The major transmission corridor is constructed from North or Northwest to East China grid. However, the development of UHV delivery channel is rather lagged behind, and the main reason for the slow construction of UHV transmission line is the delayed evaluation and approval by the governments (Zeng et al., 2014). Besides, as for the construction of high voltage transmission lines, in principle, the Central government and the State-owned grid companies have the rights to approve and implement the transmission projects above 300 kV, while the local governments and local grid companies are responsible for the transmission projects of 220 kV. However, in reality, the conflicts among responsibilities, rights and interests of relevant authorities are salient, and it directly affects the planning authoritativeness and social effects (Luo et al., 2012). Furthermore, since the power trading volume is determined by central and local government based on scheduled planning, the flexibility of transmission adjustment flexibility is rather low. Consequently, the power that generated from different sources is difficult to be dispatched, which has caused the ineffectiveness of UHV transmission line in China (Ming, Lilin, Qiannan, & Yingjie, 2016).

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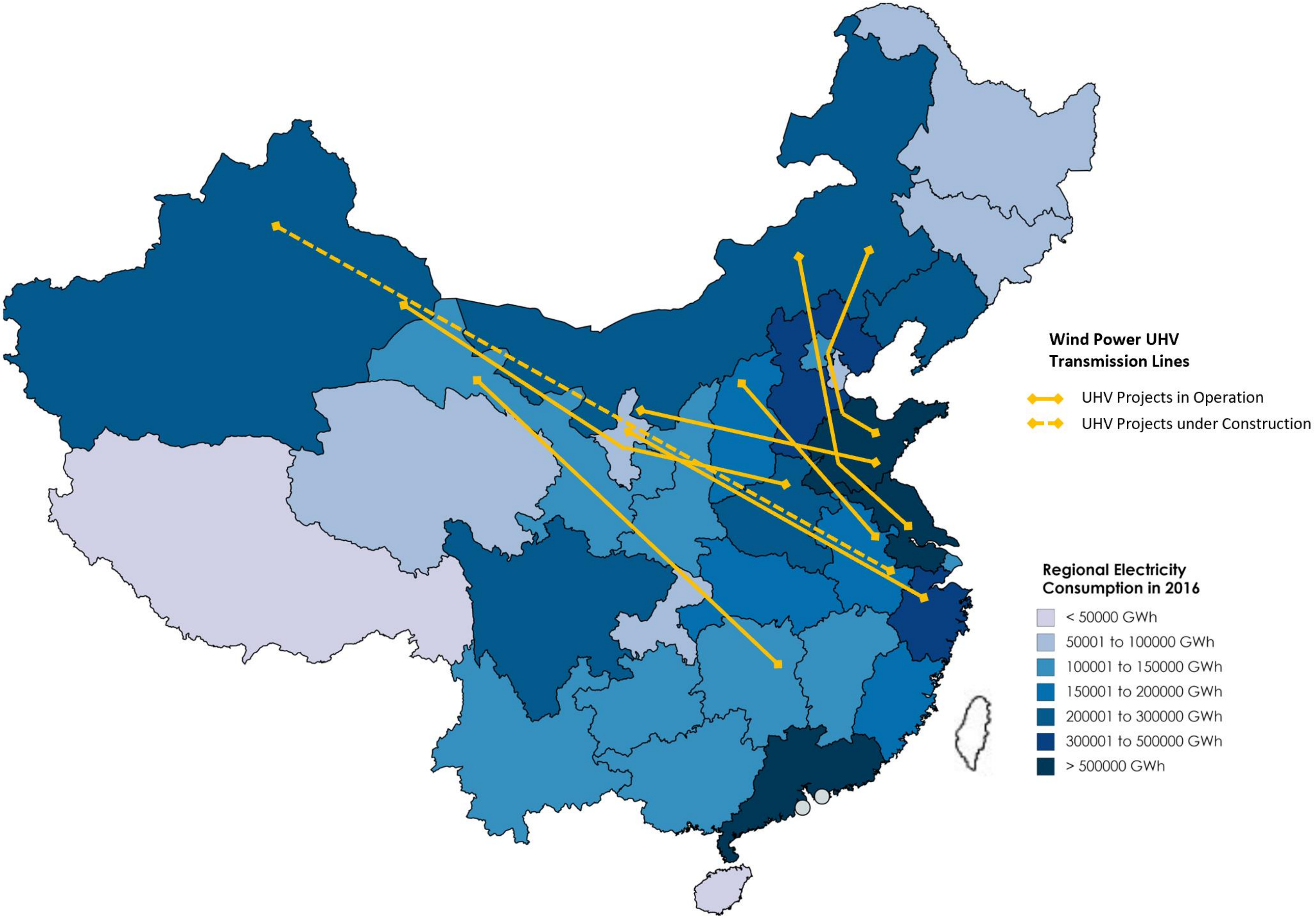
[6] UHV refers to +1000kV and ±800kV power transmission (SGCC, 2018).

Figure 2.3 Wind power and thermal power UHV projects in operation and under construction.



2.3. Data Collection

The datasets of cumulative wind installed capacity (in MW) and annually added wind installed capacity (in MW) are collected from Chinese Wind Energy Association (CWEA, 2016). The datasets of national and regional coal consumption (in million tons), gross domestic product (GDP in 100 million yuan), population (in 10,000 person), electricity consumption (in 100 million kWh) are collected from the Statistical Year Book China (National Bureau of Statistics of China, 2017). The datasets of average residential electricity sale price are collected from the State Electricity Regulatory Commission (SERC, 2017). Based on the original datasets, this study has further translated into per capita form. Electricity intensity (in kWh/yuan) and GDP per capita (yuan) are two derived datasets. Where the electricity intensity refers to the cost of converting energy into GDP. All the datasets used in the regression model is described and summarized in Table 2.2. and detailed description are explained as follows:

Table 2.2 Descriptive Statistics on Variables

	Minimum	Maximum	Mean	S. D.
FIT price (yuan/kWh)	0.47	0.7292	0.6017	0.0399
Wind resource (TWh)	2.3	56.5	21.7568	15.2458
Coal (million tons)	3.32	409.27	124.157	93.4538
GDP per capita (yuan)	5376.461	118127.6	36118.14	22443.61
Electricity price (yuan/kkWh)	337.85	648.17	505.1244	61.7042
Electricity intensity (kWh/yuan)	0	0.5205	0.1152	0.0750

2.3.1. Dependent Variables

When assessing the wind policy effectiveness, cumulative installed wind capacity or annually new-added wind capacity are two common dependent variables used by other researchers. As stated by these researchers, the cumulative installed wind capacity and the growth of wind capacity reflect the level of wind development in specific regions (Jenner, Groba, & Indvik, 2013; Menz & Vachon, 2006; Upton & Snyder, 2017). This thesis considers the cumulative wind installed capacity to illustrate an overall long-term wind power development trajectory, whereas the annually added wind capacity is considered to illustrate a dynamic and short-term wind power development trajectory.

2.3.2. Independent Variables

The FIT prices and wind resource potentials are two crucial policy design elements in wind energy policies, thus their efficacies are important to be assessed. Zhao et al. (2016) have assessed the effectiveness of price policies and non-price policies on stimulating the wind development in China, FIT policy has been selected to represent the price policy and *Renewable Energy Law* as well as *Medium and Long-term Development Plan of Renewable Energy* are selected to represent target-based non-price policy which also signify the Government's willingness to promote wind energy. However, no relevant researches have focused on the variations and classifications of FIT policy for a concrete analysis on the rationality of policy design elements, although some empirical and theoretical researches have drawn a conclusion that FIT policy is much more significant on promoting wind energy development than non-price policies (Carley, 2009; Menanteau, Finon, & Lamy, 2003). Therefore, verifying the hypothesis a) and b) is a crucial step to increase the policy confidence or to figure out underlying policy defects. This study uses dummy variables to distinguish the high/low FIT price and the rich/poor wind resource of datasets. To eliminate the nearly colinear matrix problem, the benchmark of high/low FIT price is set as the average FIT prices over 2005 to 2016 in 31 provinces, municipalities and autonomous regions. Thus, the dummy variable to categorize high/low FIT price is defined as:

$D_1 = 1$ for FIT is equal to or higher than 0.6017 yuan, and 0 otherwise;

For categorizing rich/poor wind resources, the dummy variable is defined as:

$D_2 = 1$ for regions in Category I, II and III, and 0 otherwise.

2.3.3. Control Variables

2.3.3.1. Coal Consumption

Nowadays, the electricity generation in China is still highly dependent on coal combustion. Coal-fired power accounts for 75% of the total power generated, among which around 30% are for residential use (J. Wang, Wang, Zhu, & Li, 2018). Since wind resource is intermittent, thus completely substituting coal is difficult at present, but the penetration of wind power seems to be able to alleviate the dependency on coal (Yin et al., 2017a). The cross-price elasticity is found to be positive in Bloch et al. (2015)'s research when conducting the fuel substitution from coal to renewable energy. Therefore, this study chooses the amount of coal consumption to capture the energy substitution variable.

2.3.3.2. GDP per capita

Carley (2009) stated that the economic performance is an influential factor to affect the power demand, and the argument that the development of wind energy is associated with economic growth is supported by some studies (Fotis, Karkalakos, & Asteriou, 2017; Roula Inglesi-Lotz, 2016; Lehr, Lutz, & Edler, 2012). Therefore, it is rationale to include economic factor as a control variable to evaluate the effectiveness of FIT policy. However, In the Chinese context, a causality relationship analysis by Cheng et al. (2013) indicated that the increase in electricity consumption in China would stimulate the increase of GDP, but not vice versa. Xia and Song (2017b) have conducted an econometric assessment to evaluate the effect of wind power generation on local economy over year 2005 to 2011, and proved that the additional installation of 1MW wind capacity would stimulate more than 2200 RMB in GDP per capita, which is consistent with Cheng et al.'s study. The indicators of economic performance applied by researchers usually consist of GDP growth rate, GDP per capita, income elasticity and employment rate. This thesis employs GDP per capita as the indicator due to the consideration of the large amount of population in China.

2.3.3.3. Average Residential Electricity Price

Residential tiered electricity pricing (RTEP) mechanism is formally adopted by China since 2012, and the price adjustment is influenced by the Government regulation, grid companies, power companies as well as end users (C. Wang, Zhou, & Yang, 2017a). The electricity price consists of pool purchase price, the transmission and distribution price and the retail power price, and it is divided into three tiers in China of which the first tier guarantees the most basic electricity demand from a household (Lin & Jiang, 2012). The SERC has issued the report entitled *"Annual Electricity Price Execution and Settlement Briefing"* and adopted the unit of "yuan/kkWh" to measure the average residential electricity price in different regions, thus this thesis continued to use the dataset in the unit of "yuan/kkWh" as the same with SERC. Several studies have showed the impact of on-grid wind power accommodation on the electricity price in some countries. Brancucci Martinez-Anido et al. (2016) indicated that due to the increase of wind power accommodation, the electricity price would decrease whereas the electricity price volatility would increase in the US. Badyda and Dylik (2017) analysed the data of electricity market in Poland, the UK, France and Italy and concluded that the low penetration of wind power during winter periods would double or triple the electricity price. Bell et al. (2017) suggested to utilize the low marginal cost effect of wind power to induce the merit order in Australian electricity market and justified that the increase of wind power on-grid would lower the electricity price. The similar conclusions are drawn by Jaisankar et al. (2011) in Germany and Unger et al. (2018) in Denmark. However, in China, there is no relevant studies investigating the correlation of wind power accommodation and electricity price, thus this thesis has done a pioneering work.

2.3.3.4. Electricity Intensity

Energy intensity is a term used to describe the energy efficiency of a country's economy (Mahmood & Ahmad, 2018), convergence analysis is usually conducted to study the energy intensity among a set of countries, and authors could provide policy implications or forecast future energy consumption, and the mechanism attributed to energy intensity is rather complex (Vaona, 2013). Nevertheless, as a sub-strand of energy intensity, electricity intensity is a much less diverse term and has drawn attention by some researches, and it is measured by the ratio of electricity consumption to the total output (Gutiérrez-Pedrero, Tarancón, del Río, & Alcántara, 2018; R. Inglesi-Lotz & Blignaut, 2012). Therefore, this study employs electricity intensity rather than energy intensity as a control variable, and another reason is witnessed as the wind energy is harvested for generating electricity, so using electricity intensity is much more proper and understandable.

2.4. Methodology

2.4.1. Panel Data Regression Model

One national-level dataset and 31 regional-level datasets are collected in this study. As aforementioned, the 31 datasets will be divided into six groups with accordance to the power grids. A panel data regression model is more appropriate than the pooling model because the fixed sample is observed over the time period rather than randomly picking up. The formula of panel data regression model is developed as follow:

$$WC_{it} = \alpha_i + \beta_1 D_{it} + \beta_2 X_{it} + \varepsilon_{it} \qquad (2)$$

Where $\mathrm{i} = 1, 2, 3 \ldots \mathrm{N}$ and denotes the cross sectional individuals being observed; $\mathrm{t} = 1, 2, 3 \ldots \mathrm{T}$ and denotes the time period; WC_{it} represents the cumulative wind installed capacity and annually added wind installed capacity, D_{it} represents a K-dimensional vector of independent variables, it should be noted that at nation-level the dummy variables are used as aforementioned to verify two hypothesises, but at the region-level, we used the logarithm value of wind resource to and original value of FIT prices to avoid the collinearity problem. X_{it} denotes a K-dimensional vector of control variables; $\beta_1 \;\; and \; \beta_2$ are $\mathrm{K} \times 1$ coefficient vectors of independent variables and control variables, respectively; and the slopes are independent of i and t; α_i denotes the regional entity intercepts and ε_{it} denotes the error which varies over i and t.

2.4.2. Hausman Test

The Hausman Test (Hausman, 1978) is applied to determine whether a random-effect model or a fixed effect model should be used. The null hypothesis of the Hausman test is the appropriateness of random effect model, but if the p-value is less than 0.05, the null hypothesis should be rejected thus the fixed effect model is more appropriate. The Hausman test suggested either fixed-period-effect model or random-period-effect model for different datasets of panel models in this study (Table 2.3.). The main difference between these two effect models is that the fixed-period-effect model emphasizes on the specific effect of each year, whereas the random-period-effect model emphasizes on the variation among year groups (Yan Li & Jiao, 2013). Random effect model assumes the observations in the data set is a random sample from the population and the results of the random effect model can be generalized to the whole population. But fixed effect model does not assume so and the results obtained can only be applied the observations included in the regression analysis.

Table 2.3 Hausman Test Results

	Model I (Dependent variable: Cumulative wind capacity)				Model II (Dependent variable: Annually added wind capacity)			
i	Test summary	Chi-Sq.	Chi-Sq. d.f.	Prob.	Test summary	Chi-Sq.	Chi-Sq. d.f.	Prob.
Nationwide	Two-way random	0	5	1	Period random	9.745534	7	0.2035
North	Period random	0	6	1	Period fixed	14.505772	6	0.0245
Northeast	Period random	0	6	1	Period fixed	58.414302	6	0.0000
Northwest	Period random	0	6	1	Period fixed	39.052971	6	0
South	Period Random	0	6	1	Period random	9.169133	6	0.1643
East	Period fixed	26.800098	6	0.0002	Period random	0	6	1
Central	Period fixed	18.109697	6	0.0060	Period random	8.740990	6	0.1887

2.5. Results and Discussions

The results of panel data regression with the dependent variable of cumulative wind installed capacity and annually added wind installed capacity, respectively are summarized in Table 2.7. and Table 2.8. According to the results, conclusions and discussions could be drawn as follows:

2.5.1. At National-level: Hypotheses a) and b) are proved

Statistically, significant positive effect of FIT price and wind resource is found on stimulating both the cumulative and annually added wind installed capacity at the national-level. In other words, the increase of wind installed capacity at the national level is associated with a higher FIT price at the benchmark of 0.6017 yuan/kWh, and is also associated with the location of wind farms that are constructed in rich wind resource areas (Category I, II and III). This finding could verify the effectiveness and the rationale of FIT policy design, that the classification of four wind resource areas and the FIT price has succeeded to facilitate the wind power development. Investors are motivated by the tangible and foreseeable profits, so constructing wind farms in rich wind resource areas is more risk-averse and becomes their initial alternative in deciding the location. However, without distinguishing into four-tier FIT prices, the wind power development in southern China and eastern China could hardly be facilitated, and the heavy burden in the load centre of electricity consumption regions could not be alleviated. Indeed, according to the data extracted from the China Statistic Yearbook, the poor wind resource areas such as Yunnan (7970 MW), Guizhou (3785 MW) and Guangdong (3537 MW) in South China grid, Jiangsu (6080 MW) and Fujian (2509 MW) in East China grid, as well as Hunan (2824 MW) and Hubei (2473 MW) in Central China grid have been promoted effectively. This policy design could release the electricity consumption burden in the poor wind resource areas, because according to China Statistical Yearbook 2016 (data accessible up to year 2015), these areas are the central loads of electricity consumption in China in year 2015, which are clustered in North China grid (25.2%), East China grid (23.8%), Central China grid (17.4%) and South China grid (16.7%). Reversely, the abundant wind resource areas share only less than 17% of the national total electricity consumption (with Northwest China grid of 10.6% and Northeast China grid of 6.3%).

Table 2.4 Model I estimation results (Dependent variable: cumulative wind installed capacity)

	Nationwide	North	Northeast	Northwest	South	East	Central
Constant	-244.111*** (55.996)	-2.184 (7.000)	-14.620*** (1.557)	-70.327*** (7.171)	-0.395 (8.916)	35.498*** (9.420)	-24.047** (9.151)
FIT price	0.563*** (0.103)	-6.117** (2.604)	-3.143** (1.264)	-7.287** (3.202)	2.504 (2.893)	12.862 (8.642)	-1.136 (4.809)
Wind resource	2.199*** (0.410)	0.776 (0.842)	-0.941* (0.488)	1.789 (1.334)	1.364 (1.274)	-0.499 (1.616)	0.080 (0.535)
Coal	0.263 (0.222)	2.284*** (2.604)	3.507*** (0.520)	-1.585*** (0.581)	-2.369 (1.411)	0.676 (1.124)	0.416 (0.710)
GDP per capita	2.495*** (0.500)	2.872*** (0.652)	0.125 (0.218)	4.343*** (0.794)	8.545*** (1.417)	1.298 (1.167)	1.544 (1.226)

Electricity price	0.169 (1.198)	-3.682 (2.571)	5.146*** (0.779)	21.851*** (0.794)	-13.043*** (4.541)	-17.943*** (3.562)	6.713*** (2.010)
Electricity intensity	0.446 (1.107)	-8.974** (3.759)	-10.953*** (1.403)	3.902*** (0.829)	14.848** (5.675)	8.105 (20.946)	1.988 (10.701)
Obs.	300	60	30	50	50	50	60
Model	Panel EGLS	Panel EGLS	Panel EGLS	Panel EGLS	Panel EGLS	Panel least squares	Panel least squares
R-Sq.	0.756	0.702	0.947	0.709	0.793	0.842	0.889
Adj. R-Sq.	0.750	0.668	0.933	0.668	0.764	0.772	0.851

Table 2.5 Model II estimation results (Dependent variable: annually added wind installed capacity)

	Nationwide	North	Northeast	Northwest	South	East	Central
Constant	-278.547*** (45.647)	77.018*** (16.633)	5.262 (8.913)	-31.246* (16.397)	14.890 (12.403)	46.855*** (10.763)	-33.836** (14.190)
FIT price	0.568*** (0.172)	-2.665 (3.140)	-3.896 (6.169)	-20.013*** (5.699)	0.967 (3.955)	-5.185 (4.068)	-10.781* (6.376)
Wind resource	1.554*** (0.241)	-1.057 (1.175)	4.166 (2.343)	0.060 (1.560)	2.303 (1.701)	0.573 (1.593)	1.469* (0.803)
Coal	1.092*** (0.121)	3.461*** (1.067)	-5.001 (3.388)	-1.913 (0.858)	-2.205 (1.857)	1.398 (1.105)	-0.090 (1.022)
GDP per capita	0.770** (0.322)	-2.813** (1.253)	-1.352 (1.158)	0.662 (1.831)	6.243*** (1.184)	0.783 (1.020)	0.850 (1.392)
Electricity price	0.518 (1.177)	-23.763*** (4.832)	3.977 (3.546)	16.090*** (4.400)	-14.904** (5.918)	-17.044*** (3.894)	13.893*** (4.131)
Electricity intensity	2.547*** (0.848)	-24.333*** (5.902)	9.212 (13.433)	2.340** (0.955)	4.795 (7.678)	-29.252 (18.458)	-20.430 (13.633)
Obs.	267	54	27	45	45	45	51
Model	Panel EGLS	Panel least squares	Panel least squares	Panel least squares	Panel EGLS	Panel EGLS	Panel EGLS
R-Sq.	0.614	0.842	0.909	0.892	0.579	0.699	0.678
Adj. R-Sq.	0.603	0.785	0.802	0.841	0.512	0.651	0.634

2.5.2. At regional-level: the effects of FIT price and wind resource are alleviated compared with national-level and possesses regional differences

At regional level, the negative effect (significance level of 5%) of FIT price on the cumulative wind installed capacity is found in North China grid, Northeast China grid and Northwest China grid, which means that the increase of cumulative wind installed capacity is associated with the decrease of FIT price. However, the negative effect of FIT price is only found on the annually added wind installed capacity in Northwest China grid (significance level of 1%) and slightly on the Central China grid (Significance level of 10%). As for the wind resource, although it has a significant effect on the national-level of wind installed capacity, the effect on the regional-level is extremely slight (significance level of 10%), and could only be found on the cumulative wind installed capacity in Northeast China grid and annually added wind installed capacity in Central China grid.

2.5.3. Effects of Control Variables

2.5.3.1. Coal consumption is an important determinant in Northern China

This conclusion can be explained by the following reasons. First, the urbanization process is witnessed a regional divergence across China, as the use of coal is gradually replaced by natural gas in more urbanized areas, whereas the Northern regions are still coal-dominated consumption pattern (Herrerias, Aller, & Ordóñez, 2017). According to the data of the Statistical Yearbook China, the coal consumption continued to increase from 2638.65 million tons to 4364.54 million tons during period 2005 to 2012, and started to slightly drop to 4254.76 million tons in 2015. Over the past years, the grid share of coal consumption was gradually decreased in most of the regional grids except North China grid and Northwest China grid, with the share of coal consumption increased from 34.97% to 35.06% and 6.67% to 12.39%, respectively. Especially for North China grid, the effect of coal consumption is positively significant on both cumulative and annually added wind installed capacity. Second, the dissemination of other renewables such as nuclear power and hydro-power plays a vital role as substitutional energy in Central, Southern and Eastern China. The Three Gorges Hydropower Station is the largest hydropower station in China and it accounts for 52.3% of the country's total hydropower installed capacity (X. Li, Chen, Fan, & Cheng, 2018), and the electricity is mainly sold to Central China grid, South China grid and East China grid. As for the nuclear power plant, it is said that by 2020, China's nuclear power plant will be responsible for 6% of the national energy capacity (Hsiao & Chen, 2018).

It is surprising to find that the effect of coal consumption shows positive sign on wind installed capacity in North China grid and Northeast China grid, which implies that the increase of wind installed capacity in these two grids is associated with the increase of coal consumption. This could be explained by three aspects. First, the wind curtailment rate in China is severe. In year 2014, about 6.8% of wind generation is curtailed and that was an improvement. However, the wind curtailment problem was more severe in year 2015 and 2016, with 13.8% and 14.5% of wind generation abandoned, respectively. The wind curtailment rates are extremely severe in Hebei, Inner Mongolia, Gansu, Xinjiang, Liaoning, Jilin and Heilongjiang, and most of them are the leading regions in terms of installed capacity and are also abundant wind resource areas. By comparison, the wind curtailment rate in Germany is 0.7% in year 2012, and is less than 3% in Ireland, Italy and Spain in year 2013 (IEA, 2017). Second, the construction work of grid power connection is still lagging behind. The inconsistency between wind power generation and grid power planning results in difficulty of wind power accommodation, thus, a large amount of wind power is abandoned by wind farms. The most severe regional grids are Northwest China grid (44413 GWh), North China grid (36498 GWh) and Northeast China grid (15851 GWh) cumulated from year 2013 to 2016 (NEA, 2017). Third, the substitution effect of coal-fired power on wind power may not exist in some power output regions such as North and Northeast China grid, because the electricity demand in these regions can hardly be self-fulfilled although the wind power is abundant, as a result, it triggered more consumption of coal-fired power. Therefore, it is evident to conclude that the wind energy conversion efficiency in China is rather low, and the wind power is insufficient to satisfy the increasing demand in Northern regions, thus the statement of "the increase of wind installed capacity is associated with the increase of coal consumption in Northern regions" is to some extent reasonable. However, it should be noted that this association is statistically-based, given that sociological research has found that the substitution of one natural resource for another often does not happen as anticipated because of political and economic factors (Greiner, York, & McGee, 2018).

2.5.3.2. Economic performance is an important determinant in North, Northwest and South China regions

The GDP per capita reflects the regional household income characteristics and population characteristics. Peng et al. (2010) indicates that a raising income plays a vital role in energy transition process, families with a higher household income are more insensitive to fuel price and more willing to substitute traditional fuel energy with modern ones. In addition, GDP per capita could also reflect household population characteristics. The elderly is converged in regions with lower energy transition process, and normally they are vulnerable groups without enough capacity to make a living, thus the economic feasibility of choosing cleaner energy is weakened (Han, Wu, & Zhang, 2018). Besides, van der Kroon et al. (2013) states that rural households are affordable to purchase appliances which require specific energy resource. Regional income inequality and convergence study has indicated that seven east-coastal provinces including Shanghai, Tianjin, Jiangsu, Zhejiang, Guangdong, Shandong, and Fujian, as well as Inner Mongolia are converging into high-income regions, whereas others are low-income regions (Tian, Zhang, Zhou, & Yu, 2016). The datasets in this study suggest that Beijing (118,127[7]), Shanghai (116,440), Tianjin (114,503),

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[7] Numbers in the bracelets are in unit of yuan per capita

Jiangsu (96,747) and Zhejiang (84,528) are the top five regions regarding GDP per capita, whereas Shanxi (35,443), Tibet (34,786), Guizhou (33,127), Yunnan (30,996) and Gansu (27,587) are the least economically developed regions. Therefore, it is found that the North China, Northwest China and South China are relatively under developed and thus more sensible to energy transition. The regression results suggest positive effects of GDP per capita on wind installed capacity in North China grid, Northwest China grid and South China grid, which implies that in these regional grids, the increase of wind installed capacity is associated with the increase of GDP per capita. This is because that economic performance is correlated with power consumption (Appiah, 2018; Chiou-Wei, Chen, & Zhu, 2008; Ikegami & Wang, 2016). In the Chinese context, different types of causal relationship between power consumption and GDP are found by different researches. Liu et al. (2014) concluded that in long-term, unidirectional causal relationship from power consumption to GDP is found in eastern, central and western regions in China. However, Li et al. (2013) indicated that the causal relationship diversifies between eastern and western China, in eastern China, a unidirectional causal relationship is found from power consumption to GDP, whereas in western China, a bidirectional relationship is found. In other words, the economic growth is associated with the increase of power consumption, and wind power development is associated with the economic growth.

2.5.3.3. The effect of electricity price indicates great regional difference

The panel regression results indicate negative effects of electricity price on both cumulative and annually added wind installed capacity in East China grid and South China grid, on newly added wind installed capacity in North China grid; the results also indicate positive effects of electricity price on both cumulative and annually added wind installed capacity in Northwest China grid and Central China grid, on cumulative wind installed capacity in Northeast China grid. It is found that the effect of electricity price indicates great regional difference on wind installed capacity. In East China, South China and North China grids, the increase of wind installed capacity is associated with the decrease of the electricity price, which is as expected by studies mentioned in Section 2.3.3. However, it is interesting to find that in Northwest China, Central China and Northeast China grids, the increase of wind installed capacity is associated with the increase of electricity price. This thesis explains the differences by the following reasons. First, the influential factors affecting the RTEP design in China are the users, the power companies and the Government, whereas the Government regulation plays the most crucial role on the electricity pricing (C. Wang et al., 2017a). The users' effect is reflected by the leveraged price design of RTEP which effectively maximizes the effect of demand side, the power companies' effect is reflected by the basis of costs incurred in power generation, transmission and distribution. The effect of renewable energy on the electricity price is not significant, and the necessity for reforming electricity market to assist the integration of wind power is considered a burning issue, because the current electricity price level fails to reflect regional difference in China (C. Wang et al., 2017a; Yang, Meng, & Zhou, 2018; S. Zhang, Andrews-Speed, & Li, 2018). Second, the wind farm capacity factors in the Northwest China, Central China and Northeast China grids are estimated to be the lowest three compared to other grids, according to the datasets of this thesis, the average wind capacity factor over year 2013 to 2016 in these three grids are 11.1%, 11.6% and 15.3%, respectively; whereas the grids of the highest wind capacity factors are the East China grid (18.9%) and the North China grid (17.2%). This to some extent could prove that the efficiency of wind power connected to grid is rather insufficient and low in those three grids, therefore the influence of wind power on the electricity price design remains ambiguous and insignificant. Third, other than RTEP, there exist other residential electricity pricing mechanisms in China, such as time-of-use (TOU) and real-time electricity price (RTP), in East China, South China and North China grids, most of the regions implement the combination of mixed electricity mechanisms; nevertheless, in Northwest China, Central China and Northeast China grids, most of the regions rely solely on the RTEP mechanism. Thus, under the single electricity pricing mechanism, the allocation of power resources is not as efficient as the combined mechanism (C. Wang, Zhou, & Yang, 2017b).

2.5.3.4. The effect of electricity intensity is significant outside East and Central China

The effect of electricity intensity on cumulative wind installed capacity is significant outside East and Central China grids, but the effect of electricity intensity is weakened on the annually added wind installed capacity, that is significant only in North and Northwest grids. Negative effect of electricity intensity on wind installed capacity is found in North grid and Northeast grid, which implies that the increase of wind installed capacity is associated with the decrease of electricity intensity in these two grids. However, positive effect of electricity intensity on wind installed capacity is found in Northwest grid and South grid, which indicates that the increase of wind installed capacity is associated with also the increase of electricity intensity in these two grids. Electricity intensity reflects the energy efficiency of regional economy, and it is expected that a lower electricity intensity depicts a more energy efficient economy (Dong, Sun, Hochman, & Li, 2018). In China, the highest electricity intensity regions are clustered in North and Northwest grids, e.g., Ningxia (0.3659)[8], Qinghai (0.3238), Gansu (0.1944), Guizhou (0.1741), Shanxi (0.1698), Xinjiang (0.1541), Inner Mongolia (0.1455) and Hebei (0.1267), whereas the lowest electricity intensity regions are clustered in East and Central China grids. However, the results suggest adverse effect of electricity intensity on wind installed capacity in North and Northwest grids. The most influential determinants of electricity intensity in China are considered the substitution effect, besides, the budget effect which refers to the electricity tariff and the technology effect which expresses the imported technology for primary power generators, are proved as only little effect on electricity intensity (Zha, Zhou, & Ding, 2012). Substitution effect is found as the driving effect on electricity intensity which represents the neutralization of the capital cost, labour cost and the energy price, the increase of electricity intensity is associated with the increase of labour cost, whereas is associated with the decrease of capital cost and energy price. In

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[8] Numbers in the bracelets are in unit of kWh/yuan, and represent the average value over 2005 to 2016.

Ouyang et al. (2018)'s research, industry agglomeration feature changes through eastern China to western China, that is from capital-intensive industry to labour-intensive industry. The labour-energy substitution effect as well as the capital-energy substitution effect are considered the crucial factors to explain the changing trend of electricity intensity. Substituting labour with energy in China will raise electricity intensity, because the energy price is controlled to remain low by the government. On the contrary, substituting energy with capital yields the decline in electricity intensity in eastern China and central China, whereas will trigger the raise in electricity intensity in western China (Tan & Lin, 2018).

2.6. Chapter Conclusion

This thesis has evaluated the effectiveness of wind FIT policy in China with respect to the development of cumulative wind installed capacity and annually added wind installed capacity over Year 2005 to 2016. By raising a doubt that whether the classification of wind resource areas and FIT prices is reasonable and effective or not, this thesis came up with two hypothesises: a): Wind capacity increases if wind farms are constructed in regions of rich wind resource; b): Wind capacity increases if wind farms are constructed in regions of higher FIT prices. A panel data regression model is employed and the dependent variables are cumulative wind installed capacity and annually added wind installed capacity, respectively, as the former could depict a long-term wind power development trajectory and the latter could capture the dynamic fluctuation. The independent variables are wind resource and FIT price, and dummy variables are applied when assessing the effectiveness of FIT policy at national-level, whereas at regional-level, the logarithm value of wind resource and the original value of FIT price are used to avoid collinearity. Control variables include average residential electricity price, coal consumption, GDP per capita and electricity intensity. The test results have proved that both hypothesises are valid at the national-level, but at the regional-level, the results indicate huge differences and could be concluded into four aspects: 1) coal consumption is an important determinant in regions located in North, Northeast and Northwest China grids; 2) economic performance is an important determinant in regions located in North, Northwest and South China grids; 3) the effect of electricity price indicate great regional differences; 4) the effect of electricity intensity is significant outside regions located in East and Central China grids.

CHAPTER THREE

The Policy Design of the Wind Power Feed-in Tariff Policy

3.1. From Social Theory to Public Design

Linder & Guy Peters (1989) are the earliest researchers who generalize the social theory to public policy design. They pointed out that applying macro-level theories to policy design is lack of inadequate guidance to one or more aspects of a three-dimensions policy framework. The concept is demonstrated in Fig. 3.1, causes, values and instruments are defined as necessary elements in social policy design. The causes of a policy refer to some policy problems which would be useful for designing interventions. The attributes of causes' characteristics are summarized in Table 3.1. The value of a policy refers to the value-laden goals such as social justice, social equality and equity. The policy instruments are referred as tools to assist the policymaker in achieving the policy value. The basic appraisal criteria of the policy instruments are summarized in Table 3.2.

Figure 3.1 Macro-theories and three-dimensions policy framework.

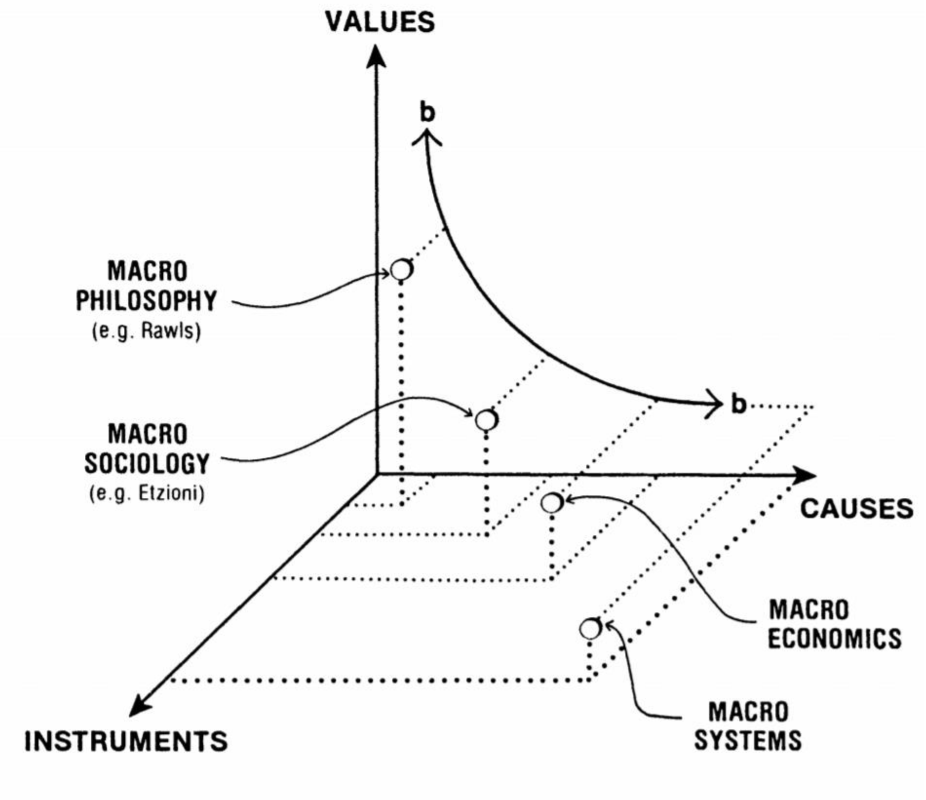


Table 3.1 The attributes and descriptions of causes in policy design (Linder & Guy Peters, 1989).

Attributes	Description
Scale	A policy is effective unless some threshold size is achieved.
Collective Consumption Goods	Goods may influence the manner in which they must be treated in the policy process.
Certainty	It is certain or relatively certain in capturing some environmental changes, where less certain about others.
Predictability	Certain changes are predictable.
Independence	The degree to which a policy-maker can or cannot determine the outcomes of a policy.

Table 3.2 The basic appraisal criterial of policy instruments (Linder & Guy Peters, 1989).

Basic Appraisal Criteria	Instruments
Relevancy	Does the instruments relevant to the policy problem?
Distortion	Does the implementation of the instruments cause distortion of other social or economic process
Structural Integrity	Is it based on internally consistent principles?
Reproducibility	Has it been successful in similar circumstances?
Tractability	Can it be easily used?
Accessibility	Is information available to make the instrument work and monitor its effects?
Flexibility	Can it work in a changing environment?
Common Sense	Does tuition tell that it will be effective
Credibility	Does those administering the instrument believe it will be effective?
Efficiency	Is it cost-effective?

3.2. Generic Conceptual Design Framework (GCDF)

Herder & Stikkelman (2004) have proposed a Generic Conceptual Design Framework (GCDF), which aims to develop an actor-integrated mechanism to create support for policymakers by using industrial and economic data. Fig. 3.2 illustrates their general framework. It should be noted that this theoretical framework is inapplicable when the actors are considering entering a new industry. The explanation of the GCDF process is summarized in Table 3.3.

Figure 3.2 The diagram of GCDF (Herder & Stikkelman, 2004).

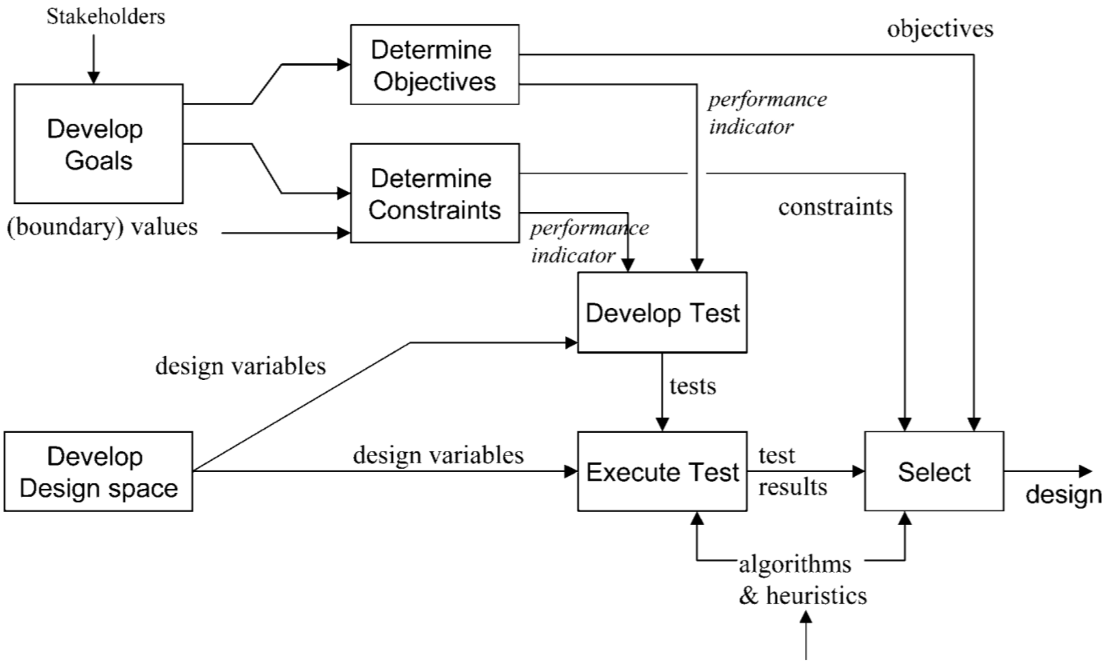


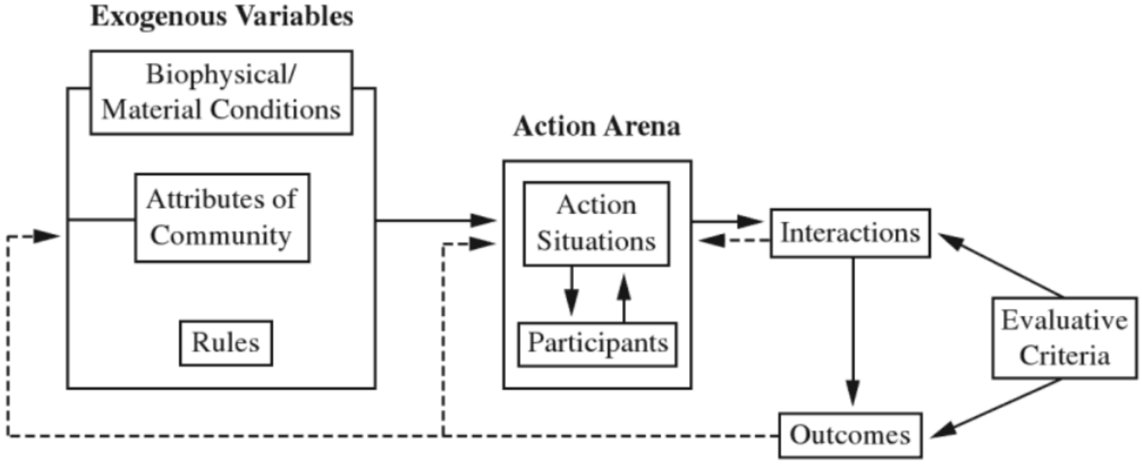
Table 3.3 Explanation of the GCDF process (Iychettira, Hakvoort, & Linares, 2017).

Develop goals, objectives and constraints	Affordability, sustainability, security of supply, fair competition
Develop space	To determine the design elements from decision variables.
Tests	To understand the outcomes with corresponding design space.
Select	To select a configuration which meet the design goal.

3.3. Institutional Analysis and Development (IAD)

Ostrom (2005) has introduced an Institutional Analysis and Development (IAD) policy design mechanism, which could reflect more about the sophisticated design process in reality. The framework of the IAD is demonstrated in Fig. 3.3, the feature of this mechanism is that the outcome can feed back to the participants and the situation and may transform both over time, and it can also affect the exogenous variables.

Figure 3.3 The framework of IAD policy design mechanism.



According to the IAD policy, there are three endogenous factors affecting the structure of an action arena:

I. Rules used by participants to order their relationship. The term "rule" can be explained by four senses – regulations (laid down by an authority), instructions (refers to an effective strategy for how to solve a problem), precepts (a maxim for prudential or more behaviour) and principles (empirical test).

II. Attributes of the biophysical or material conditions. The biophysical or material condition refers to the feasible actions on the operational level, whether the actions are physically possible and how the actions can affect the outcome. For instance, whether a subsidy policy could be technology neutral or specific, or location neutral or specific (Iychettira et al., 2017).

III. Attributes of the community. At the community level, the policymakers may decide on the price warranty, quantity warranty, cost and expenditure and contract type.

3.4. Applying the policy design framework to wind power policy design

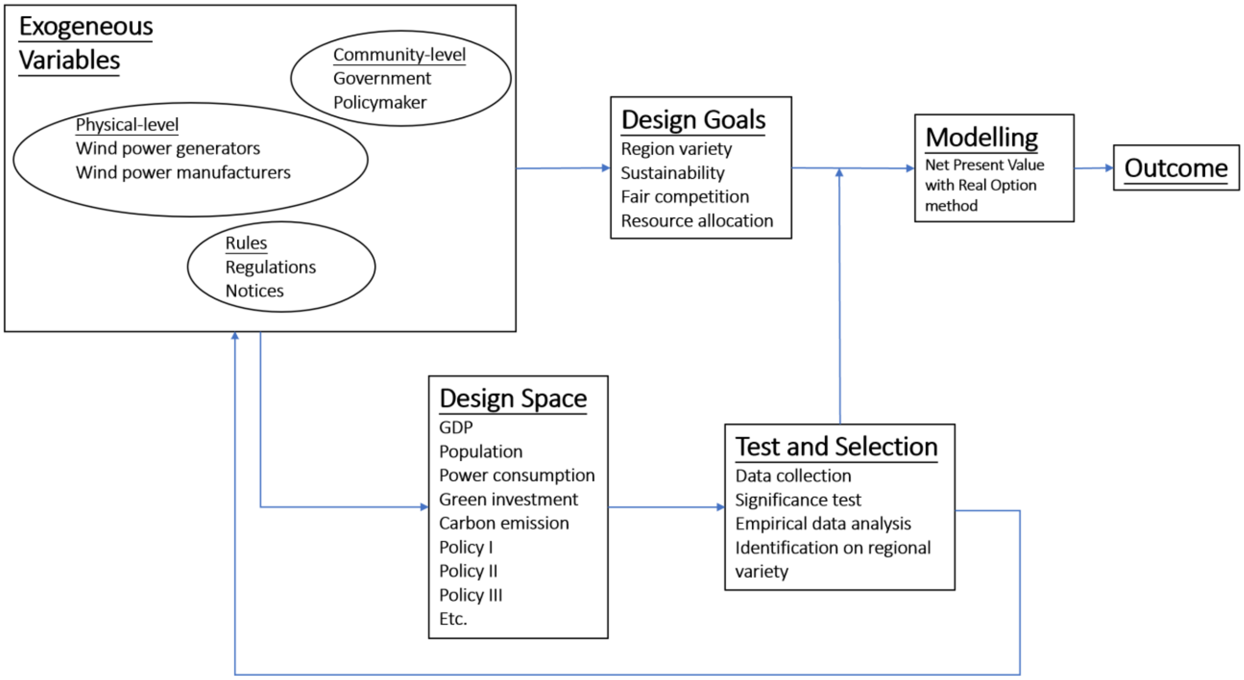
This study has integrated the design concept of GCDF and IAD to develop a novel policy design framework that could be applied to wind power policy. The framwork of the policy design machenism is illustrated in Fig. 3.4. The exogeneous variables are devided into conmmunity-level, physical-level and rules.

Community-level: According to Chapter Two, the Chinese society is highly concentrated and strictly top-down ruled by the central government, so the dominator at the community-level is the central government. In particular, the wind FIT policy is related to a series of price adjustment, so the FIT price stipulated by the central government is the benchmark price that should be implemented in each region. Under this condition, the central government is also the policymaker. Subjected to the certain circumtance just mentionsed, the policy design under the proposed framework is effective if and only if the community-level is relevant to an independent authority.

Physical-level: According to Chapter One, the core wind power policies issued by the central government have consolidated the position of domestic wind power generators and manufactorers. The investment option of those wind power enterprises are not only affected by the profitbility of FIT policy, but also affected by their enterprise-based managerial flaxibility and uncertainty. The model is established using an Real Option method which will be introduced in Chapter Four.

Rules: The rules that manages the relationship among participants in the wind power industries mainly refer to the regulations and notices that are promulgated by the central government. Besides, the regulations and notices that considered in the model should be highly relevant to the design goals.

Figure 3.4 The proposed framework of wind FIT policy design.



Besides, the desgin goals, design space, and test and selection procedures are included in the framework:

Design Goals: Reforming the current wind FIT policy is the main goal, which is associated with considering region variaty, sustainability, fair competition and resource allocation. As indicated in Chapter 2.4, regional differences are found significant to affect the cumulative and newly added wind installed capacity. Therefore, a region-variaty-inclusive wind FIT policy should be achieved by policy reforming. By integrating the policy with region variaty, a fair competition environment could be constructed and resource allocation could be redistributed. The sustainability of social, economy and environment could be further achieved.

Design Space: This step aims to identify the policy design elements in the model. The effect of the indicators in different aspects to the development of wind power in China has been identified in Chapter Two. It is concluded that the power consumption, carbon emission, economic situation, population and dominated fuel type in different regional power grids may impose different significant level on the wind power development. Therefore, the desgin space of the policy model has considered the aforementioned aspects as determinants. Besides, investment in environmental treatment has also been considered in the model, which includes the investment in industrial pollution and investment in projects of environmental protection. Apart from these socio-economic features, the design space has also considered the relevant policies (Policy I, Policy II and Policy III) that have been issued after the FIT policy. Policy I refers to the *Notice on the National Carbon Emission Trading Market Construction Plan (Power Generation Industry)* (NDRC, 2017a), and the open of national carbon emission market has stimulated the growth of economy, as well as alleviated the carbon prices (Lin & Jia, 2020). Policy II refers to the *Notice on Guaranteeing the Purchasing of Electricity Generated by Using Regenerable Energy Resources in Full Amount* (NDRC, 2015a), which aims to tackle the overcapacity problem arising from the rapid development of wind power. Policy III refers to *the Notice on Value-added Tax Policy of Wind Power Generation.* As analysed in Chapter One, this policy has contributed to the wind power enterprise localization in China, and the tax exemption arrangement will benefit the wind power investors constantly. The application of the relevant policies will be explained in Chapter Four.

Test and Selection: This step aims to refine the exogenous variables and design space in order to capture the useful data and information into the final model. Data collection, significance test, empirical data analysis and identification on regional variety are the main methods in this step. Once the testing results failed to conform with the design goals, the selection of exogenous variables and design space will be refreshed until the satisfactory results are generated.

Modelling: While the prerequisite data and information are synthesized and refined, the modelling of the proposed wind power policy could commence. In this policy reforming, the Net Present Value integrated with Real Option method will be applied. The details are presented in Chapter Four.

Outcome: The outcome of the model created under the proposed wind power policy framework is the suggested six-regional-power-grid-based FIT benchmark price. The outcome will also be discussed in Chapter Four.

3.5. Policy Design Elements

Cross-sectional analysis is applied to analyze causal relationship between the design elements in design space and the installed wind power. The procedure is similar to the panel data analysis that has been conducted in Chapter Two, so the theory of this methodology will not be repeated in this chapter. The equation applied to cross-sectional analysis is shown below:

$$\log P_w = \beta_0 + \beta_1 \log P_t + \beta_2 \log P_s + \beta_3 \log P_h + \beta_4 \log GDP + \beta_5 \log Invest + \beta_6 \log E_{carbon} + \beta_7 Policy\_I + \beta_8 Policy\_II + \beta_9 Policy\_III + \varepsilon_t \qquad (3)$$

Where P_w, P_t, P_s and P_h refer to the amount of cumulative installed wind power capacity, thermal power capacity, solar power capacity and hydropower capacity, respectively. GDP, Invest and E_{carbon} represent Gross Domestic Product, investment in environmental treatment and the amount of carbon emission, respectively. Policy I, Policy II and Policy III refer to the implementation of aforementioned wind power supporting policies in design space. The results of the cross-sectional analysis are presented in Table. 3.4. It is found that all the variables considered in the model have significant influence on the wind power development except the amount of carbon emission. The increase of installed wind power capacity is associated with the increase of installed thermal power capacity, hydropower capacity, investment in environmental treatment and the implementation of three relevant policies. On the contrary, the increase of installed wind power capacity is associated with the decrease of installed solar power capacity and GDP. As reported by Statistical Yearbook China 2019, the share of installed thermal power capacity, hydropower capacity, solar power capacity and wind power capacity to the total installed capacity of power generation are 60.21%, 24.92%, 9.19% and 9.70%, respectively.

Table 3.4 Results of cross-sectional analysis.

Independent Variable	Coefficient	t-Statistic	Prob. (S.E.)
Installed thermal power	3.5283	7.9023	0.0042*** (0.4465)
Installed solar power	-0.0544	-5.3104	0.0130** (0.0102)
Installed hydropower	0.9735	3.7890	0.0322** (0.2569)
GDP	-1.8106	-3.2245	0.0484** (0.5616)
Investment in environmental treatment	1.5398	10.3334	0.0019*** (0.1480)
Carbon emission	-0.0528	-0.1151	0.9157 (0.4589)
Constant	-13.5161	-14.6703	0.0007*** (0.9213)
Policy I	0.2704	9.6223	0.0024*** (0.0281)
Policy II	0.0991	5.7242	0.0106** (0.0173)
Policy III	0.2088	15.2403	0.0006*** (0.0137)
R^2	0.99		
F	0.000***		
No. of observations	13		

3.6. Chapter Conclusion

This chapter has introduced the expansion from social theory to public policy design. The policy design concept of Generic Conceptual Design Framework (GCDF) and Institutional Analysis and Development (IAD) are integrated in this chapter, and a novel policy design framework for wind FIT policy is developed. The novel wind FIT policy framework consists of a section of exogeneous variables and a section of design characteristics. The exogeneous variables include the stakeholders at community-level and at physical-level, and the regulations and notices that manages the relationship between them. The design characteristics include the design goals, design space, test and selection, as well as modelling. Besides, a cross-sectional analysis is applied to determine the policy design elements in the design space. It is highlighted that three relevant policies are significant influential factors to affect the development of installed wind power capacity, and these policies are treated as design elements in the modelling process.

CHAPTER FOUR

The Regional-Power-Grid Based Policy Mechanism

4.1. Introduction

In January 2019, the National Development and Reform Committee (NDRC) stipulated the *Notice on work related to wind power and photovoltaic power generation connected to grid without subsidy* (NDRC, 2019a). The attempt of the *Notice* expresses the government's intention to promote a low or no subsidy policy mechanism on renewable energy power development in the future. The reform of the wind FIT benchmark price in China has been concerned by the government for a long time. The highest administrative organ NDRC has promulgated a series of notices including the notices related to consecutive adjustment on wind FIT benchmark price level and executing nationwide carbon emission trading scheme (NDRC, 2009b, 2011, 2014, 2015b, 2015a, 2016b, 2017c, 2017b, 2019b), in order to promote the wind power development in China to achieve a sustainable environment. As sub-ordinary bodies of NDRC, the National Energy Administration (NEA) and the Ministry of Finance (MF) has also stipulated affiliated policies (MF, 2015; NEA, 2013) to assist in encouraging wind farm construction projects.

In recent years, some researchers around the world have proposed new price policy mechanisms to adjust the renewable energy FIT price level. Yang and Ge (2018) introduced a dynamic distributed solar power FIT pricing model that considered the unit generation cost, profit and tax. The results suggested a 5-tier incentive mechanism based on the irradiation time from 0.3245-1.0708 CNY/kWh in 2017, to 0.2159-0.7125

CNY/kWh in 2020. Barbosa et al. (2018b) applied the NPV and real option method to identify the fixed or unfixed minimum price guarantee with regulatory uncertainty. Their study pointed out that a fixed FIT could induce the investment even the price was lower than market price because it provided a risk-free environment. Antweiler (2017b) employed a methodology which combines FIT and capacity-augmentation-tariff to analyse the optimal price mechanism on wind and solar energy. His study recommended that the price differentiation mechanism was economically meaningful according to different types and locations of wind farms. Devine, Farrell, and Lee (2017a) applied a risk aversion model to simulate the optimal FIT mechanism from investors' and policymakers' perspectives, and concluded that the flat-rate FIT and premium FIT were optimised in different risk-aversion situations. Kim and Lee (2012a) employed NPV method to optimize four FIT payoff structures for solar power generation and added in economic constraints to develop an option-like featured model.

The policy reform is imperative. Different from previous studies, this study has proposed a brand-new FIT policy mechanism – Regional-power-grids-based FIT policy mechanism, which is the continuity of the authors' preliminary research (R. Zhang, Ni, Shen, & Wong, 2019a). This study applied the NPV method and the RO method to model the cash flow, project value and risks in enterprise's managerial flexibility and uncertainties during warranted life of a typical 45 MW wind farm which comprises of 18 units of 2,500 kW wind turbines. The feasibility of the methodology in renewable energy field could be proven by existing researches (Barbosa et al., 2018; Fagiani, Barquín, & Hakvoort, 2013; Kim & Lee, 2012b; Lin & Wesseh, 2013; Penizzotto, Pringles, & Olsina, 2019; Rigter & Vidican, 2010; Ritzenhofen & Spinler, 2016; Schmidt, Lehecka, Gass, & Schmid, 2013; Wesseh & Lin, 2016; Yang & Ge, 2018; M. M. Zhang, Zhou, Zhou, & Liu, 2016) .

4.2. Methodology

Section 2.1 comprehensively introduces the concept of applying NPV method considering RO. The conventional NPV method only calculate the discounted cashflow subtracts the upfront investment cost, but in this thesis, the value of RO which counts in the enterprise's managerial flexibility and uncertainty is also considered as a loss and subtracted from the discounted cash flow. The cashflow of a wind farm project comprises of the profit from selling on-grid wind power, the profit from carbon emission trading scheme, the profit from curtailed wind compensation, the expenditure on the operation and maintenance (O&M) cost and tax payment. Relevant policies which can support this thesis's calculation are referenced in each sub-section. The principle of employing RO is explained in Section 2.2. the value of RO represents the risk of an enterprise's managerial flexibility and uncertainty to invest in the wind power project immediately instead of waiting or delaying.

4.2.1. Net Present Value Method

In this thesis, NPV is calculated by means of Eq. (4) on the basis of the following equation:

$$V^{NPV} = \sum_{t=0}^{L} \frac{CF_t}{(1+r)^t} - RO - CI_t \tag{4}$$

Where

$$CF_t = ELE_t + CER_t + CUR_t - OMC_t - TAX_t \tag{5}$$

V^{NPV} stands for the amount of net presenet value, CF denots yearly cash flow of the project and CI represents capital investment. RO represents the enterprises' managerial flexibility and uncertainty. The value of RO is calculated by means of quantifying the systematic risk and idiosyncratic risk using the Black-Scholes Model. The wind turbine life span is L and the investment is settled in yeat t. r denotes the discount rate.

The calculation of yearly cash flow includes the profits from selling wind power to the grid ELE, the profits from carbon trading mechanism CER, the compensation on the curtailed wind power due to systematic failure CUR_t, the operation and maintenance cost OMC, as well as the tax expenditure TAX.

4.2.1.1. Profit from Selling Grid-Connected Wind Power

The profit for the wind farm investors on selling the wind power to the regional power grids is calculated by the following equations:

$$WF_t = \frac{H_i}{h} * 100\% \tag{6}$$

$$WF_{t+1} = WF_t * (1 - R_{dep}) \tag{7}$$

$$GE_t = P_t * N * WF_t \tag{8}$$

$$ELE_t = GE_t * FIT_t \tag{9}$$

$$FIT_{t+1} = FIT_t * e^{-R_{fit}} \tag{10}$$

Where H_i stands for the annual wind farm utilised hour for grid-connected wind power generation, and h denotes the annually total hour. Wind farm capacity factor WF_t is calculated by H_i and h. GE_tdenotes the grid-connected power that generated from wind energy, P_t denotes the rating power of a wind turbine system, R_{dep} denotes the wind turbine system depreciation rate. FIT_t stands for the feed-in-tariff price level at year t and it follows an exponential descending trend with rate value of R_{fit}. The decreasing rate R_{fit} is calculated according to the actual changing rate over the past years that stipulated by the NDRC.

Since the North China grid, Northeast China grid and Northwest China grid are facing a severe wind curtailment problem, the wind curtailment rates are getting even worse over the past three years (R. Zhang, Ni, Shen, & Wong, 2019b).

4.2.1.2. Profit from Carbon Emission Trading Scheme

According to *BP Statistical Review of World Energy* (2017), the total carbon emissions in China at the end of 2017 was 9232.6 million tons, which accounts for 27.6% of world's output and is on the rise for consecutive years. Among all the power consuming segments, electricity and heat production contributes around 50% of the carbon emission, thus make carbon emission reduction a critical role of energy transition from traditional fuels to renewables. On December 19, 2017, the NDRC (NDRC, 2017b) promulgated *the Notice on the National Carbon Emission Trading Market Construction Plan (Power Generation Industry)*, which represents the start-up of nation-wide carbon trading system. The *Notice* stipulated more than 1700 enterprises (with a majority of power generation enterprises) should commit the obligation of carbon trading process. Therefore, the implementation of this policy will discourage the investor's choice on coal-fired power plants, but make the wind farm investment choice more attractive (X. Zhao, Yao, Sun, & Pan, 2018). Therefore, the North China grid, Northeast China grid and Northwest China grid should consider this factor as a potential influence on the amount of coal consumption.

The profit of wind farms from trading carbon emission certificate (CER_t) is calculated in accordance with the NDRC's (NDRC, 2016a) standardized combined margin emission factor of a certain grid in year t $(EF_{grid,t})$:

$$CER_t = EF_{grid,t} * GE_t * P_{c,t} \tag{11}$$

$$EF_{grid,t} = W_{BM} * BM_{grid,t} + W_{OM} * OM_{grid,t} \tag{12}$$

The $EF_{grid,t}$ is calculated by the weighted average of the build margin emission factor $(BM_{grid,t})$ and operational emission factor $(OM_{grid,t})$, the values are summarised in Table 4.1. The operating margin is the emission factor of the thermal power plants and all plants serving the grid that cannot be characterized as "must run". The build margin is the emission factor of a group of recently built power plants. The weights are denoted by W_{BM} and W_{OM}, respectively (China Environmental United Certification Center (CEC), 2016; SecuritiesIndustrial, 2013). The methodology ACM002 referred to the Global Climate Change Research Institute of the Tsinghua University targets at large-scaled (installed capacity above 15MW) wind farm projects has stipulated the value of W_{BM} and W_{OM} as 0.25 and 0.75, respectively (D. Liu, 2012).

Table 4.1 Values of build margin emission factor $(BM_{grid,t})$ and operational emission factor $(OM_{grid,t})$ in six regional grids in China. It is noted that the values are updated by weighted average method to year 2014 (NDRC, 2016a).

	$BM_{grid,t}$	$OM_{grid,t}$	$EF_{grid,t}$
North China grid	1.0000	0.4506	0.58795
Northeast China grid	1.1171	0.4425	0.61115
Northwest China grid	0.9316	0.3467	0.492925
Central China grid	0.9229	0.3071	0.46105
East China Grid	0.8086	0.5483	0.613375
South China Grid	0.8676	0.3071	0.447225

$P_{c,t}$ represents the carbon price. The NDRC has issued the *Notice on Pilot Work on Carbon Emissions Trading* and announced seven pilot provinces and cities to launch the carbon trading scheme in October 2011 (NDRC, 2011). During the pilot operation, the carbon price is fluctuated between 5 and50 RMB/tCO_2e (Boer de, Renato, Huw, & Qian, 2017). In December 2017, the NDRC released *the National Carbon Emission Rights Trading Market Construction Plan* to open up the nation-wide carbon trading mechanism and will be practised in 2019 (NDRC, 2017b). Therefore, referring to the historical data (Ministry of Industry and Information Technology, 2019), this study assumes 50 CNY/tCO_2e as carbon trading price in North, Northeast and Northwest power grids, and 30 CNY/tCO_2e in Central, East and South power grids.

Based on the previous research works (Brauneis, Mestel, & Palan, 2013; Fuss, Johansson, Szolgayova, & Obersteiner, 2009; X. Zhao et al., 2018; L. Zhu & Fan, 2011), $P_{c,t}$ follows a Geometric Brownian Motion (GBM) as:

$$\mathrm{dP}_{c,t} = \mu_c P_{c,t}\, dt + \sigma_c P_{c,t}\, dW_{c,t} \tag{13}$$

Where μ_c and σ_c denote percentage drift of carbon price and percentage volatility of carbon price, respectively. $W_{c,t}$ represents an incremental Wiener process and obeys normal distribution $W(t) \sim \mathrm{N}(0, \varepsilon_c^2 t)$, and ε_c denotes the parameter of the Wiener process.

4.2.1.3. Profit from Curtailed Wind Power Compensation

In 2015, the NDRC has enacted the *Notice on Guaranteeing the Purchasing of Electricity Generated by Using Regenerable Energy Resources in Full Amount* (NDRC, 2015a), which stipulated that the amount of curtailed renewable power due to grid connection failure or constrained dispatch quota could receive full compensation as the same rate of FIT price. This policy offsets the investment risk caused by systematic failure that should not be responsible by wind power investors, therefore, it encourages the wind power investors who is concerned about this issue to be more confident to enter the market. From 2015 on, the curtailed amount of wind power is required to be recorded in official document because of severe wind power curtailment situation emerged in China. North, Northeast, Northwest and South China grids are currently on record with curtailed amount of wind power, and this study has calculated the wind curtailment rate according to the official data and employed the value in the model to calculate the profit from curtailed wind power compensation:

$$CUR_t = \frac{R_{cur} * GE_t}{(1 - R_{cur})} * FIT_t \tag{14}$$

Where R_{cur} denotes the wind curtailment rate and CUR_t represents the profit from curtailed wind power compensation to the wind power investors.

4.2.1.4. Expenditure on O&M Cost and Tax Payment

In 2009, the Minister of Finance stipulated *the Notice on Value-added Tax Policy of Wind Power Generation*, which provided favourable tax preferential incentives for enterprise income tax (EIT_t) and value-added tax (VAT_t). The *Notice* announced that for wind energy project in China, the VAT_t has been deducted from 17% to 8.5% while the EIT_t has been exempted during the first three years, and then deducted from 33% to 15% during the second three years.

$$OMC_t = (GE_t + \frac{R_{cur} * GE_t}{(1 - R_{cur})}) * UOMC_t * 10^3 \tag{15}$$

$$TAX_t = VAT_t + EIT_t \tag{16}$$

$$VAT_t = (ELE_t + CER_t + CUR_t) * R_{vat,t} \tag{17}$$

$$EIT_t = [(ELE_t + CER_t + CUR_t) * (1 - R_{VAT,t}) - OMC_t] * R_{EIT,t} \tag{18}$$

The expenditure on O&M cost is presented in Eq. (15), where $UOMC_t$ denotes the unit operation and maintenance cost. The expenditure on tax payment is calculated by Eq. (16) to Eq. (18), where the $R_{VAT,t}$ and $R_{EIT,t}$ denote the rates of value-added tax and enterprise income tax, respectively.

4.2.1.5. Investment Cost

The upfront investment cost is calculated as below:

$$CI_t = UC_t * P_t * N * 10^3 \tag{19}$$

$$\mathrm{d}UC_t = \mu_u UC_t\, dt + \sigma_u UC_t\, dW_{u,t} \tag{20}$$

Where UC_t represents the unit investment cost of investing a wind farm project. $\mu_u\ and\ \sigma_u$ denote percentage drift of unit investment cost and percentage volatility of unit investment cost, respectively. $W_{u,t}$ represents an incremental Wiener process and obeys normal distribution $W(t) \sim \mathrm{N}(0, \varepsilon_u^2 t)$, and ε_u denotes the parameter of the Wiener process. Eq. (20) demonstrate the GBM of the investment cost.

The value of the parameter in the model are summarized in Table 4.2.

Table 4.2 Parameters input in the NPV model.

Parameters		Description	Value	Unit	Source
r		Discount rate	0.049	Per year	(REUTERS, 2017)
L		Life span of a wind turbine	20	Years	/
h		Annually total hours	8760	Hours	(H.-P. Cheng & Yu, 2013)
H	North	Average annually operating hours	2057	Hours	(Ministry of Industry and Information Technology, 2018)
	Northeast		2152		
	Northwest		1826		
	Central		2033		
	East		2325		
	South		2012		
P		Rated wind power capacity	45	MW	Assumed
N		Number of wind farms	1	/	Assumed
R_{cur}	North	Annually wind curtailment rate in severe areas	6.32	%	Calculated by this study
	Northeast		16.62		
	Northwest		16.40		
	South		2.67		
R_{dep}		Depreciation rate	0.025	Per year	(Ragheb, 2017)
R_{fit}	North	FIT reduction rate	-2.836	%	Calculated by this study
	Northeast, Northwest		-2.899		
	Central, East, South		-1.674		
$BM_{grid,t}$		Build margin emission factor of a certain grid in year t.	Refer to Table 4.1.	tCO_2e/MWh	(NDRC, 2016a)

$OM_{grid,t}$		Operational margin emission factor of a certain grid in year t.	Refer to Table 4.1.	tCO_2e/MWh	(NDRC, 2016a)
W_{BM}		Weight of build margin emission factor	0.25	/	(D. Liu, 2012)
W_{OM}		Weight of operational margin emission factor	0.75	/	(D. Liu, 2012)
$P_{c,t}$	North, Northeast, Northwest,	Carbon trading price	50	CNY/tCO_2e	(Ministry of Industry and Information Technology, 2019)
	Central, East, South		30		
μ_c		Percentage drift of carbon price	0.03	Per year	(M. M. Zhang et al., 2016)
σ_c		Percentage volatility of carbon price	0.02	Per year	(M. M. Zhang et al., 2016)
UC_{t-1}		Unit investment cost	3650	RMB/kW	(Esmaieli & Ahmadian, 2018)
μ_u		Percentage drift of unit investment cost	-0.06	Per year	(Rigter & Vidican, 2010)
σ_u		Percentage volatility of unit investment cost	0.04	Per year	(Rigter & Vidican, 2010)
$UOMC_{t-1}$		Unit operation and maintenance cost	0.2	CNY/kWh	(M. M. Zhang et al., 2016)
$R_{VAT,t}$		Value-added tax rate	0.085	Per year	The *Notice*
$R_{EIT,t}$		Enterprise-income tax rate	0.25	Per year	(C. bin Li, Lu, & Wu, 2013)

4.2.2. Real Option Method

As illustrated by Eq. (1), RO is introduced as a part of the NPV calculation. The value of RO represents "an enterprise's managerial flexibility and uncertainty", which could offset the limitation of using the conventional NPV method only (Pringles et al., 2015). Although the conventional NPV method is very useful for simulating the investment performance of large-scale wind power projects, it neglects the value of the "waiting time" for investors to respond. In China's market context, the wind power FIT benchmark price descends annually and quickly, so investors prefer to wait and observe or defer their investment rather than investing immediately. Investment in a secondary industry is regarded as merely reversible, so the investors are taking every step carefully to eliminate all potential risks. Hence, under a dynamic investing environment, investors enjoy the flexibility to take advantage of the "waiting time" to formulate appropriate responses until the investment uncertainty is well solved. Nevertheless, the value during the "waiting time" cannot be measured by the NPV method (Liu and Ronn, 2020). Under this circumstance, adding RO method into the NPV method could address the "delay investment" problem, and it enables the investors to be willing to invest immediately.

The RO method has been well applied in the research field of renewable energy policy design. For example, Davis and Owens (2003) focused on the optimization of the renewable energy research and development (R&D) funding level, and they used the RO method to determine whether additional values will be created if the R&D funding levels vary. Kim et al. (2014) also focused on the R&D market in wind power and applied the RO method to measure the economic value of investing in wind power R&D projects. Gollier et al. (2005) employed the RO method to compare the option value of managerial flexibility and uncertainty between a large-scale and a small-scale nuclear power plant and provided plant size-related insights for decision making. Similar comparison studies on hydropower and biomass power projects were completed by Bøckman et al. (2008), Fleten et al. (2007), and Wang et al. (2014). The RO method was also applied in investment evaluation, policy evaluation, and pricing design by Lin and Wesseh (2013), Penizzotto et al. (2019), Ritzenhofen and Spinler (2016), Wesseh and Lin (2016), Yang and Ge (2018), and Zhang et al (2016) .

The Black-Scholes model (BSM), binomial model (BM) and Least-Squares Monte Carlo (LSMC) are three methods to solve the RO problems. The BSM requires five key inputs (underlying asset stock price and strike price, volatility, duration to the maturity of the option, and risk-free risk) to determine the theoretical option value; conversely, the BM starts from a stock price, produces a binomial tree with up and down limits of volatility step by step until the expiration time, and finally requires a backward computation (Hoadley, 2020). The LSMC requires to use the computerized modelling to calculate the value of RO, it usually starts with a random number that is depended upon a probability distribution, and then repeat the process thousands of times. The value of RO that is calculated by LSMC method relies on the mean value of all the results (Nadarajah et al., 2017). This study chooses the BSM to calculate the value of RO because of two reasons. First, as 1002 observations are involved in this work, the BSM is more efficient that the BM because the former can reduce the computational complexity. Second, regarding the output result from the BSM and BM models, Ahmad Dar and Anuradha (2018) confirmed that the result does not show much of a difference.

4.2.2.1. Black-Scholes Model

This study has employed the Black-Scholes model to calculate the value of RO based on the empirical practices by other researchers. (Lin and Wesseh, 2013; Penizzotto et al., 2019; Ritzenhofen and Spinler, 2016; Wesseh and Lin, 2016; Yang and Ge, 2018; Zhang et al., 2016) .The RO accounts for the enterprises' managerial flexibility and uncertainty, which is regarded as a stochastic loss added to the fixed upfront payment. The Black-Scholes model includes stochastic differential equations and requires fixed inputs to operate the model. The theoretical function is expressed as follows (Black & Scholes, 1972, 1973):

$$\mathrm{RO} = P_{asset}\, N(d_1) - P_{strike}\, e^{-R_f D_t}\, N(d_2) \qquad (21)$$

Where RO denotes the value of the option, P_{asset} and P_{strike} represent the underlying asset price and strike price, respectively. R_f denotes the constant risk-free rate, which can be expressed by a 10-year China government bond yield of 3.19%. D_t denotes the duration to the maturity of the option. $N(d_1)$ and $N(d_2)$ stands for process of standardized cumulative density function. The estimation of $d_1$and d_2 can be expressed by the following equations:

$$d_1 = \frac{\ln \frac{P_{asset}}{P_{strike}} + (R_f + \frac{{\sigma_{asset}}^2}{2})\, D_t}{\sqrt[\sigma_{asset}]{D_t}} \tag{22}$$

$$d_2 = d_1 - \sqrt[\sigma_{asset}]{D_t} \tag{23}$$

Where ${\sigma_{asset}}^2$ denotes the annual volatility of underlying asset. The value of $N(d_1)$ and $N(d_2)$ fall in a range of 0 to 1, they are statistical variables representing probabilities. $P_{asset}\, N(d_1)$ is the amount that will likely be received on selling the stock at expiration, while the expression $P_{strike}\, e^{-R_f D_t}\, N(d_2)$ is the payment that the stock will probably be purchased when the option is exercised (Martin, 2017). The estimations of $d_1$and d_2 can be expressed by Eqs. (19) and (20). The establishment of d_1 is based on the Central Limit Theorem, which implies that if sufficient daily stock returns of an asset are graphed, they will form a normal distribution. $\ln \frac{P_{strike}}{P_{asset}}$ is the rate of growth from the stock price to the strike price, $R_f - \frac{{\sigma_{asset}}^2}{2}$ is the mean of the probability curve that represents what the future rate of growth will be, while $\sqrt[\sigma_{asset}]{D_t}$ is the standard deviation of the daily stock return. The calculation of d_1 is regarded as the calculation of the Z-score[9] of the normal distribution. The Z-score of $d_1$is then expresses as $N(Z) = \frac{\ln \frac{P_{strike}}{P_{asset}} - (R_f - \frac{{\sigma_{asset}}^2}{2})\, D_t}{\sqrt[\sigma_{asset}]{D_t}}$, which represents the probability of having stock price lower than strike price.

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[9] Also known as the "standard score", is the number if standard deviations by which the value of a raw score is above or below the mean value of that is being observed. Z-score is calculated as $z = \frac{x-\mu}{\sigma}$,where x is the raw score, μ is the mean of the population and σ is the standard deviation of the population.

Correspondingly, the probability of having stock price higher than strike price is referred as $N(d_1) = N(-Z) = \frac{\ln\frac{P_{asset}}{P_{strike}} + (R_f + \frac{{\sigma_{asset}}^2}{2})\, D_t}{\sigma_{asset}\sqrt{D_t}}$. In addition, ${\sigma_{asset}}^2$ is calculated by an N -asset portfolio that is established by this study:

4.2.2.2. N-Asset Portfolio Combination

This study established a portfolio containing 10 sets of stocks in different wind power industries, among which a half are wind power generators and the other half are wind turbine manufacturers. These10 enterprises are selected due to their top rankings in terms of the market share in wind power industry, and in addition they are listed companies in Mainland China or Hong Kong, so the datasets (Appendix. C) of their historical daily stock return could be collected online for further calculation and estimation, which is a very important procedure and a significant advantage of the variance-covariance approach as stated above. Table. C.1 presents the full name, stock codes of the 10 enterprises and the observation of daily stock return in calculation. Table. C.2 summarizes the descriptive statistics of the 10 stock datasets. Each set of the observed data falls within or around an absolute value of 0 of skewness and 3 of kurtosis, and the probability of Jarque-Bera test suggests to accept the null hypothesis of normal distribution (Soberón & Stute, 2017).

The portfolio combination plays a crucial role in determining the option value, because other input parameters such as duration to maturity and risk-free interest are fixed and constant. The value of underlying asset price, strike price and volatility are influenced by different portfolio combinations. In this study, we made a combination of different portfolio of N=2, 3, 4, 5, 6, 7, 8, respectively. The total number of observations is 1002.

The N-asset portfolio volatility is calculated by the following equation:

$$\sigma_{asset}{}^{2} = \sum_{i=1}^{N}\sum_{j=1}^{N} w_i w_j \sigma_i \sigma_j \rho_{(i,j)} \tag{24}$$

Where w denotes the weight of market capitalization of asset i and j in the combined portfolio, σ stands for the standard deviation of stock daily return of asset i and j and $\rho_{(i,j)}$ represents the covariance of stock daily return between asset i and j .

4.3. Results and Discussions

This section summarizes the results of the proposed FIT benchmark price that is calculated by the NPV integrated RO method. The comparison between the proposed FIT benchmark price (IRR ranges from 8% to 15%) and the current FIT price is illustrated. The comparison between the NPV method with/without the consideration of RO method is also presented. The suggested FIT benchmark price levels in 2021 and 2022 are also presented. In particular, this work builds two scenarios (I and II) that are related to two possible development of the carbon trading policy that is just implemented. As China just opened its nationwide carbon trading market, the carbon trading price mechanism remains ambiguous. What is known is that marketization is the final goal and government regulation is the tool to adjust and intervene in the market. Therefore, Scenario I demonstrates an increasing trend of carbon trading price in previous years by GBM. By contrast, Scenario II suggests a stable and constant carbon trading price. This work does not build scenarios that are related to other policies (such as tax reduction and wind curtailment compensation), because they have been implemented for a long time, the policy mechanisms are clear enough.

In addition, the total expenditure, total revenue, the project value, the average annual grid-connected wind power, and polluting emission reduction as well as the Levelized Cost of Electricity (LCOE) of wind power are also demonstrated. This section ended up with the sensitivity analysis.

4.3.1. Overall Result

The comparison of wind power FIT benchmark price between government setting and suggested value by this thesis is illustrated in Fig. 4.1 The lower bound value and upper bound value represent the wind power FIT benchmark price level that ensures the enterprise's internal rate of return (IRR) falls in between 8% and 15%. Fig. 4.1 reveals that the current government setting value in Hebei and Inner Mongolia goes beyond the lower bound, whereas the current government setting value in Liaoning goes beyond the upper bound. This finding indicates that the current differentiate FIT price of Category I and Category II is too low to attract investment in areas with abundant wind resource, which turns out a slowdown in wind farm investment in recent years and if the FIT price continues to be adjusted to a lower level by the government, consequently the stagnation in investment will emerge. On the contrast, the current government setting value in Liaoning is regarded too high, which will stimulate large amount of investment, and consequently turns out sever wind power overcapacity and curtailment problem.

Regarding other provinces, municipalities and autonomous regions, the current government setting value is considered in the safe zoon which guarantees IRR of 8% to 15% to investors. However, the current value in Gansu, Ningxia and Xinjiang is approximately near the lower bound. This finding provides the government a signal that the FIT benchmark price in these three regions should not be decreasing anymore. In addition, the differentiated FIT benchmark price in Category III is also considered too low, thus the wind energy industry in areas with relatively abundant wind resource will foreseeably encounter many bottlenecks regarding further development. Although Jilin and Heilongjiang are also classified into Category III, as they located in Northeast China grid where the suggested value by this thesis is the lowest among six regional power grids, the current government setting value is in the middle level and indicates IRR of 11% to 12%. As for the provinces, municipalities and autonomous regions that locate in Category

IV, the government setting value is found in the middle or higher level of the safe zoon. The IRR of enterprises under current FIT benchmark price is around 11% to 12% in Central and South China grid, and reaches 13% to 14% in North, Northwest and East China grid.

Fig. 4.2 illustrates the comparison between the NPV method with/without the consideration of RO method. It is found that suggested FIT benchmark price levels using the NPV integrated RO method are higher than the conventional NPV method. Since the RO method offsets the limitation of the conventional NPV method by taking the time value of managerial flexibility and uncertainty into account, the investors will be more confident to follow the price levels that are proposed by RO method immediately.

Fig. 4.3 presents the suggested FIT benchmark price range in 2021 and 2022, under two possible scenarios regarding China's carbon trading market, respectively. Since China just opened the nationwide carbon trading market, the carbon trading price mechanism remains ambiguous. What is known is that marketization is the final goal and government regulation is the tool to adjust and intervene the market. Therefore, Scenario I demonstrates an increasing trend of carbon trading price in previous years by GBM. By contrast, Scenario II demonstrates a stable and constant carbon trading price. Compare Figs. 4.3(a), 4.3(b) with Figs. 4.3(c), 4.3(d), the suggested wind power FIT benchmark price in Scenario I is lower than that of Scenario II. It is because that the increased carbon trading price will offset more expenditure than a constant carbon trading price.

The total expenditure, total revenue and NPV of project value are illustrated in Figs. 4.4-4.6, respectively. The NPV of project value is in the similar level of six regional power grids, that is because that this study uses one 45 MW typical wind farm as the model, so the numbers of wind farms in each regional power grids are not counted. The average annual grid-connected wind power and polluting emission reduction is demonstrated in Fig. 4.7.

Besides, the Levelized Cost of Electricity (LCOE) is estimated by region (Fig. 4.9). LCOE is used to measure the life cycle cost of producing each unit of the electricity (Bruck et al., 2018). The LCOE of the wind power is the ratio of the present value of the total expenditure to the amount of grid-connected wind power (Miller et al., 2017). Fig. 4.9 reveals great differences of the LCOE of wind power in six regional grids. The LCOE of wind power in the East China grid is the lowest while in the Northwest China grid is the highest. This implies that the East China grid is the most cost-effective grid to produce wind power, whereas the Northwest China grid is the least cost-effective one. Therefore, the LCOE of wind power helps the government to manage the power purchase amount with investors. It is suggested that the government should stimulate wind power investment in more cost-effective grids, and inhibit wind power investment in less cost-effective grids.

Table 4.3 is the summary of the discussions in this section. It highlights the baseline of IRR, proposed FIT benchmark price in six regional power grids under two scenarios, number of households can be fed, policy implications to the government, the investment potential for the investors as well as the suitable enterprise type to launch the project. The following sections have explained the reason of setting the acceptable IRR in each regional power grid.

Figure 4.1 The comparison between the results and the current FIT price level.

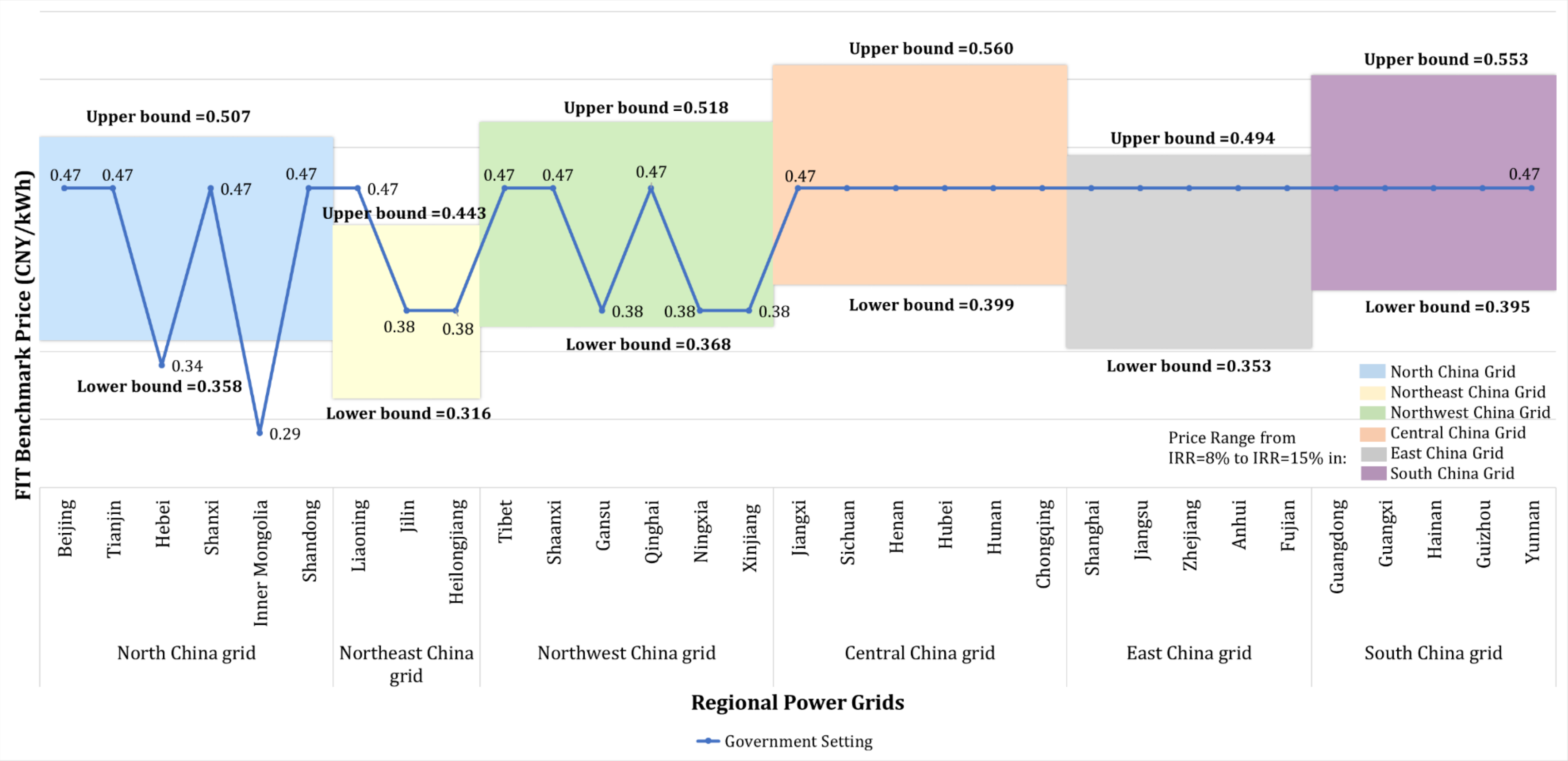


Figure 4.2 The comparison between the NPV method with/without the consideration of RO method.

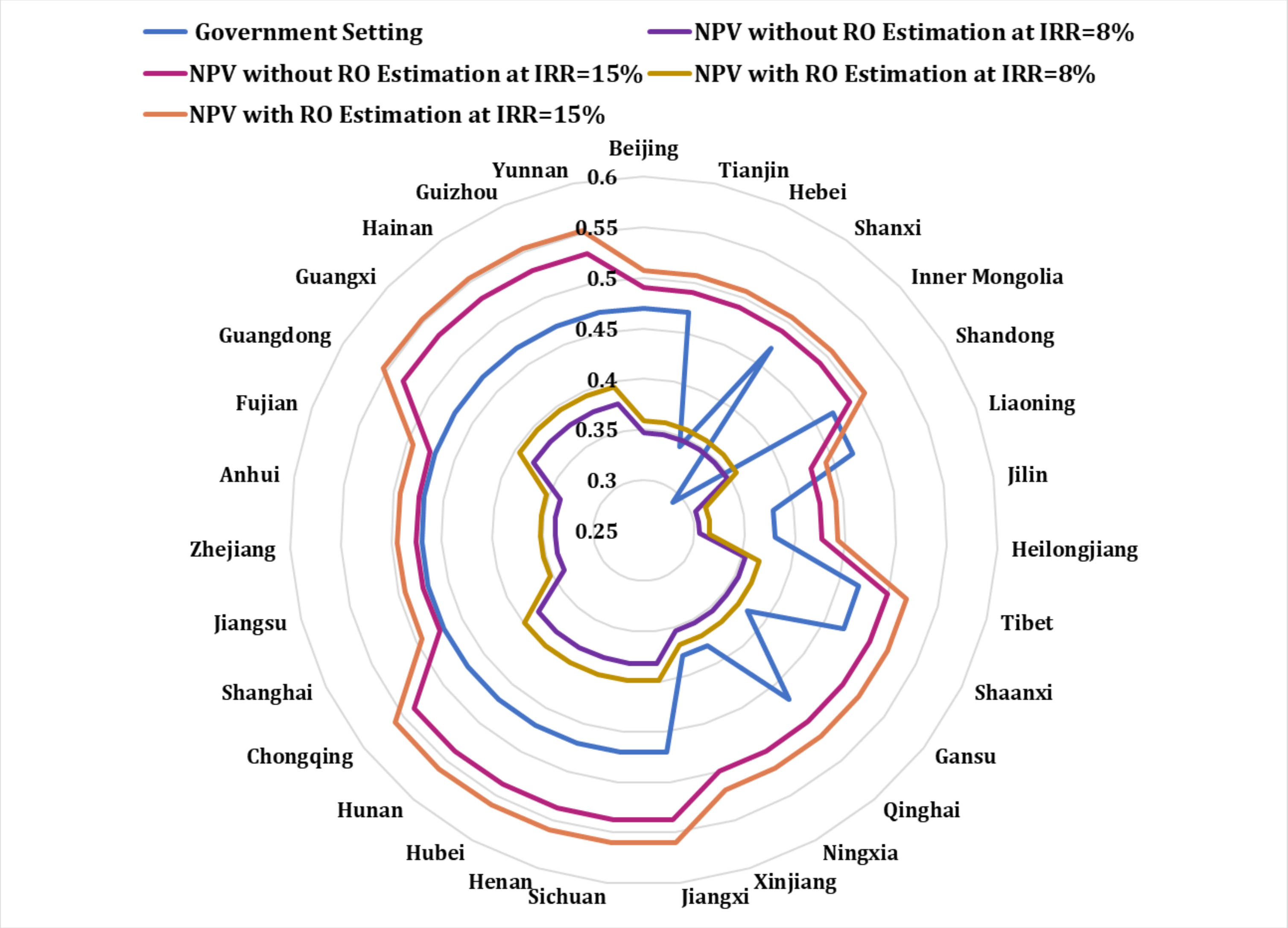
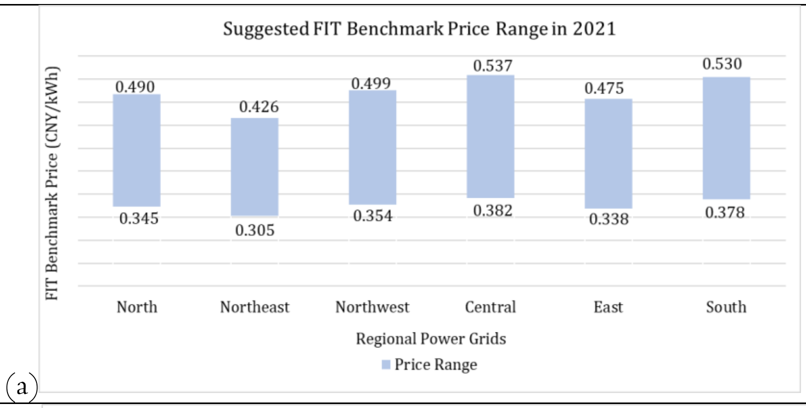
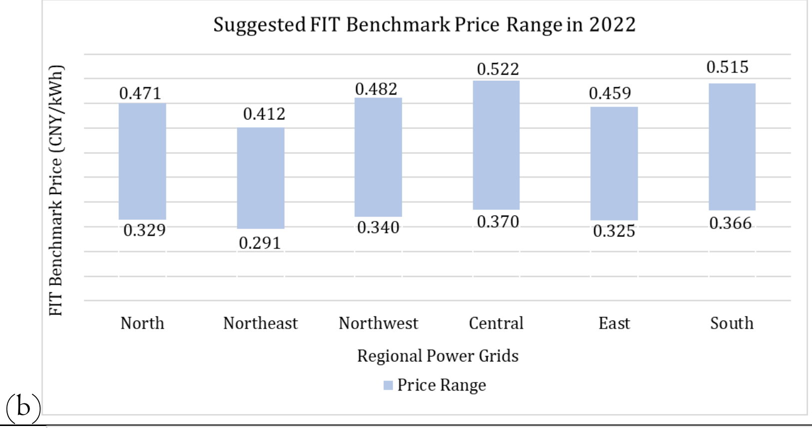
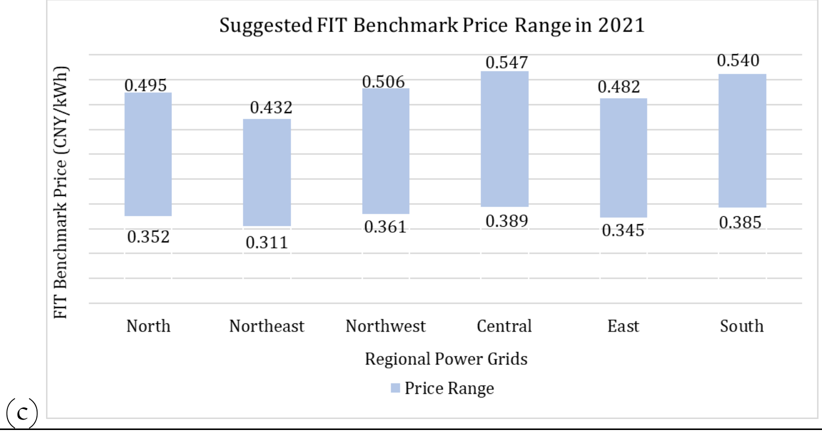
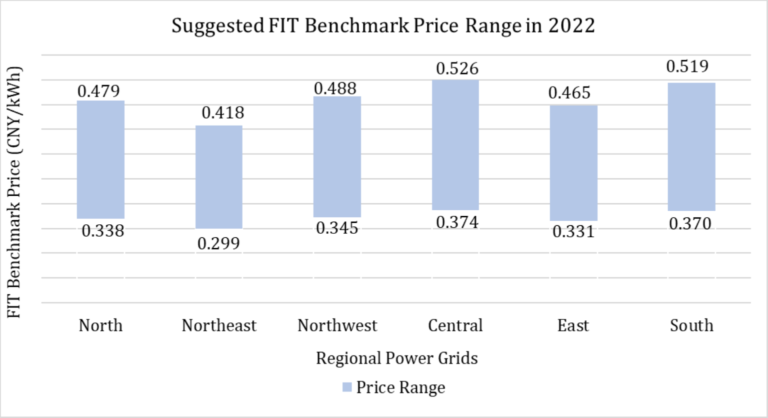


Figure 4.3 Suggested FIT price range in 2021 and 2022 under different scenarios.

Scenario I – Increasing Trend of Carbon Trading Price	
	
Scenario II – Constant Carbon Trading Price	

	(d)  Suggested FIT Benchmark Price Range in 2022 FIT Benchmark Price (CNY/kWh) 0.479 0.338 0.418 0.299 0.488 0.345 0.526 0.374 0.465 0.331 0.519 0.370 North Northeast Northwest Central East South Regional Power Grids Price Range

4.3.2. North China Grid

The differences of current FIT benchmark price levels in Category I, II and IV are simultaneously reflected in North China grid, which result in severely unbalanced IRR for investors to invest in the same power grid. 21Century Economic Report (2010) has pointed out that the baseline of IRR which is acceptable by wind farm project investors in China is 8%. However, the wind power investors may reject to invest in Hebei and Inner Mongolia since their estimated IRR under the current FIT price are 7% and 5%, respectively, below the acceptable baseline. Moreover, since the discount rate for enterprises by the Central Bank of China is 4.9%, the wind power investors in Inner Mongolia is likely to face a losing proposition.

On the contrary, the current FIT benchmark price in Beijing, Tianjin, Shanxi, Shandong (included in Category IV) is more favorable by investors, since the IRR is estimated as 14%. It is suggested that the government could lower down the IRR standard in North China grid to a certain level of IRR equals 11% to 12% (Table 4.3). The saved financial budget from these four regions could be redistributed to investors in Hebei and Inner Mongolia.

4.3.3. Northeast China Grid

The suggested FIT benchmark price level by this thesis in Northeast China grid is the lowest, with the price range falls in between 0.316 CNY/kWh and 0.443 CNY/kWh (Fig. 4.1). This is because 19.3% of the nationwide wind power is generated by Northeast China grid, but the curtailed wind power accounts for 40% of the nationwide due to grid connection failure or constrained dispatch quota. As mentioned before, the current FIT price in Liaoning is found too high as the IRR reaches 17%. Although it is favorable to investors, the negative impact will emerge if many investors are attracted to invest in Liaoning. Firstly, the overcapacity and wind power curtailment problem will be aggravated. The electricity consumption in Northeast China grid only accounts for 6% of the national total electricity consumption

(National Bureau of Statistics, 2019), which means that the electricity demand in this grid is not high. Therefore, continuing to construct wind farm in Liaoning will aggravate the overcapacity and wind power curtailment problem. To solve this problem, the need of consistency in grid planning and wind power accommodation is highlighted by a group of researchers (Luo et al., 2016a; Shen & Luo, 2015b; Si et al., 2011; Q. Wang, 2010; Wei et al., 2018; Yin, Zhang, Andrews-Speed, & Li, 2017b; Z.-Y. Zhao, Chang, et al., 2016; Z.-Y. Zhao, Chen, et al., 2016). Secondly, unnecessary government expense will be triggered. The increase of the wind farm project in Liaoning will make the government compensate more on the curtailed wind power, which is a waste of government budget that can be avoided by lowering down the FIT benchmark price of Liaoning. Since the IRR in Jilin and Heilongjiang under current FIT price is 12%. The suggested FIT price in Liaoning should be at the same level as other two provinces, Jilin and Heilongjiang, of 0.38 CNY/kWh in 2020. Furthermore, considering the low electricity demand and severe wind power curtailment in Northeast China grid, it is recommended that the IRR baseline is acceptable between 9% and 10% (Table 4.3).

4.3.4. Northwest China Grid

There are six provinces and autonomous regions in Northwest China grid under Category III and IV, respectively. The current FIT benchmark price level could satisfy an IRR of 9% in Gansu, Ningxia and Xinjiang, and IRR of 13% in Tibet, Shaanxi and Qinghai. Northwest is facing the similar circumstance as Northeast that the electricity demand is relatively low. The electricity consumption in Northwest China grid accounts for 10% of the national total electricity consumption (National Bureau of Statistics, 2019), whereas the share of the wind power installed capacity accounts for 27% of the national total amount (Fig. 4.8). Consequently, the curtailed wind power accounts for 37% of the national total amount. Therefore, this study suggests the government also lower down the FIT benchmark price in Tibet, Shaanxi and Qinghai, to the same price of that in Gansu, Ningxia and Xinjiang (0.38CNY/kWh) in 2020.

Furthermore, the IRR baseline is recommended to set between 9% and 10% in Northwest China grid (Table 4.3).

4.3.5. Central and South China Grids

The statistics and results in Central China grid and South China grid are very similar, so the implications and reflections are interpreted simultaneously in one section. Fig. 4.1 indicates that the current FIT level guarantees an IRR of 12% in both Central China grid and South China grid in 2020. The suggested lower bound value and upper bound value in these two grids are the highest among six regional power grids. In addition, both the total expenditure and total revenue (Figs. 4.4-4.5) in these two grids are the lowest. It is because the wind farm average annually operating hours in these two grids are relatively low, which are just more than the Northwest China grid, so the amount of grid-connected wind power in these two grids are relatively low. In consequence, the profit from carbon trading mechanism and selling electricity to the grid is low.

As the installed wind power capacity could be almost fully adopted in the power gird, the government should keep encouraging investors to construct wind farms in these two areas, whereas avoid excessive expansion. Therefore, it is suggested that the FIT benchmark price levels in Central and South China grids better remain with the baseline of IRR at 12% to 13% (Table 4.3).

4.3.6. East China Grid

The current FIT price in East China grid indicate an IRR of 14% for investors, which appears to be the most profitable area for constructing wind farms. However, it is surprising to find that the suggested FIT benchmark price in East China grid is even lower than North and Norwest China grids, that the upper bound is eve lower than 0.5 CNY/kWh. This indicates that the profitability in East China grid does not solely depend on the price level of FIT, but also depends on the carbon trading mechanism as explained in the last section.

This study shows that the investment potential in East China grid is enormous, since the electricity consumption only in East China grid accounts for as much as 26% of the national total consumption. Nevertheless, the cumulative wind power installed capacity merely accounts for 7% (Fig. 4.8) and the curtailed wind power is zero. This implies that the high electricity demand in East China grid highly improves the harvest of wind power, thus, this study ascertains that the baseline of future IRR for enterprises to invest should fall in between 13% and 14% (Table 4.3).

Table 4.3 Summary of the discussions.

		North China Grid	Northeast China Grid	Northwest China Grid	Central China Grid	East China Grid	South China Grid
IRR Range		11% to 12%	9% to 10%	9% to 10%	12% to 13%	13% to 14%	12% to 13%
Suggested FIT (Scenario I, unit : CNY/kWh)	Year 2021	0.390 to 0.420	0.315 to 0.332	0.368 to 0.388	0.466 to 0.489	0.431 to 0.451	0.460 to 0.483
	Year 2022	0.389 to 0.408	0.308 to 0.323	0.360 to 0.378	0.454 to 0.478	0.421 to 0.440	0.449 to 0.472
Suggested FIT (Scenario II, unit: CNY/kWh)	Year 2021	0.408 to 0.429	0.322 to 0.340	0.376 to 0.398	0.476 to0.499	0.440 to 0.461	0.470 to 0.493
	Year 2022	0.395 to 0.416	0.315 to 0.331	0.366 to 0.385	0.459 to0.481	0.425 to 0.445	0.453 to 0.475
Annually average on-grid wind power generation of a 45MW wind farm (unit: MWh)		71,716	75,028	63,662	70,879	81,059	70,147
Number of households can be fed[10]	Two-people family	58,706	61,418	52,114	58,021	66,355	57,422
	Three-people family	39,138	40,945	34,742	38,681	44,237	38,481
Reduced carbon emission (MtCO$_2$e)		45.00	54.99	37.54	32.68	49.72	32.23
Policy implications to government		FIT price in Hebei and Inner Mongolia should be raised	Consider the overcapacity and wind curtailment problem in Liaoning	Inhibiting the investment in Tibet, Shaanxi and Qinghai	The expenditure and the total revenue are the least	Profitability depend on both FIT price level and carbon trading mechanism	The expenditure and the total revenue are low
Investment potential for investors		Moderate	Low	Low	High	Enormous	High
Suitable Enterprise type		Medium-scale	Large-scale	Medium-scale	Small-scale	Large-scale	Small-scale

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[10] According to China Statistical Yearbook 2018 (National Bureau of Statistics, 2019), the annual per capita electricity consumption is 610.8 kWh.

Figure 4.4 Estimated total expenditure under different value of IRR

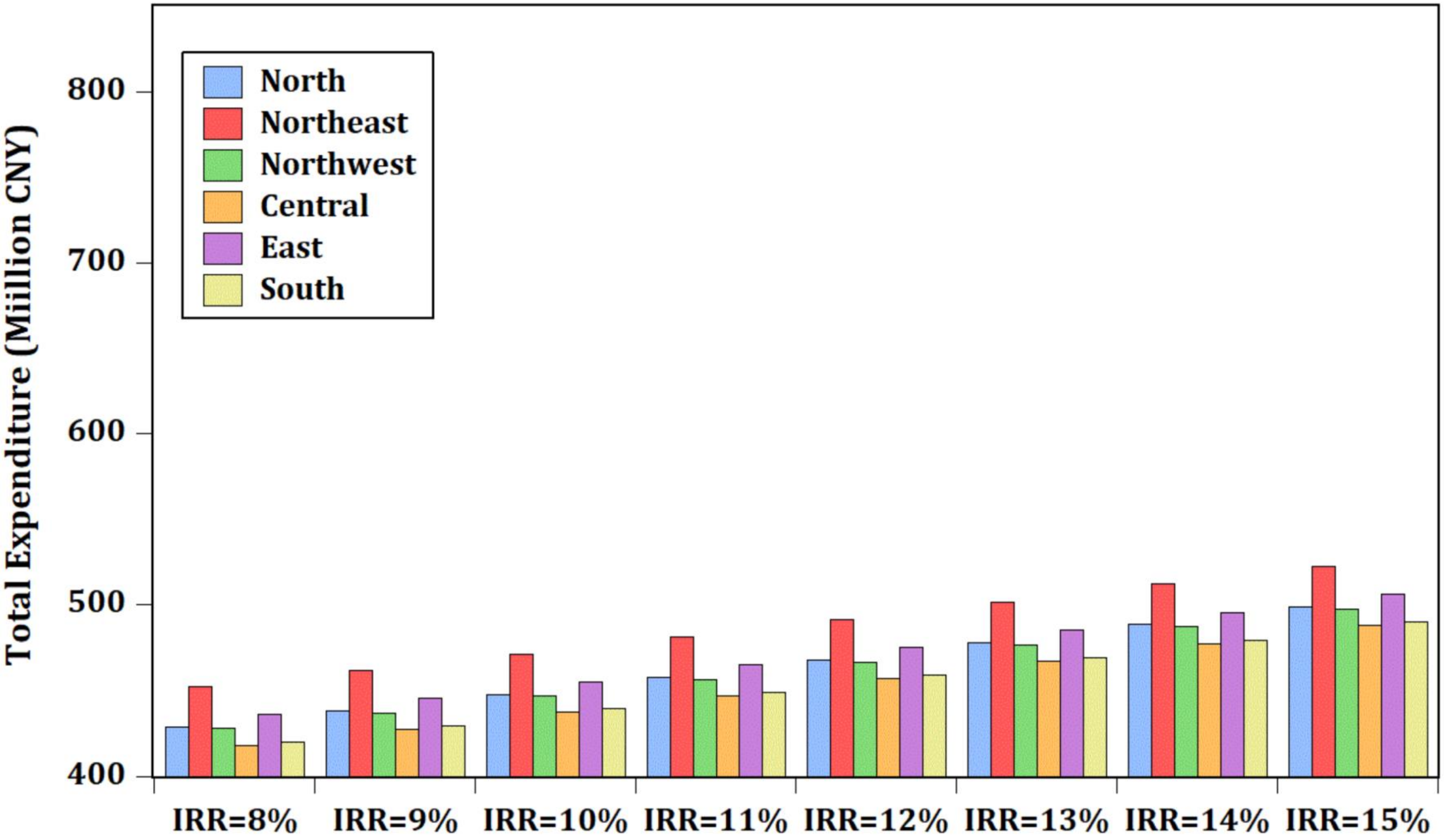

Figure 4.5 Estimated total revenue under different value of IRR

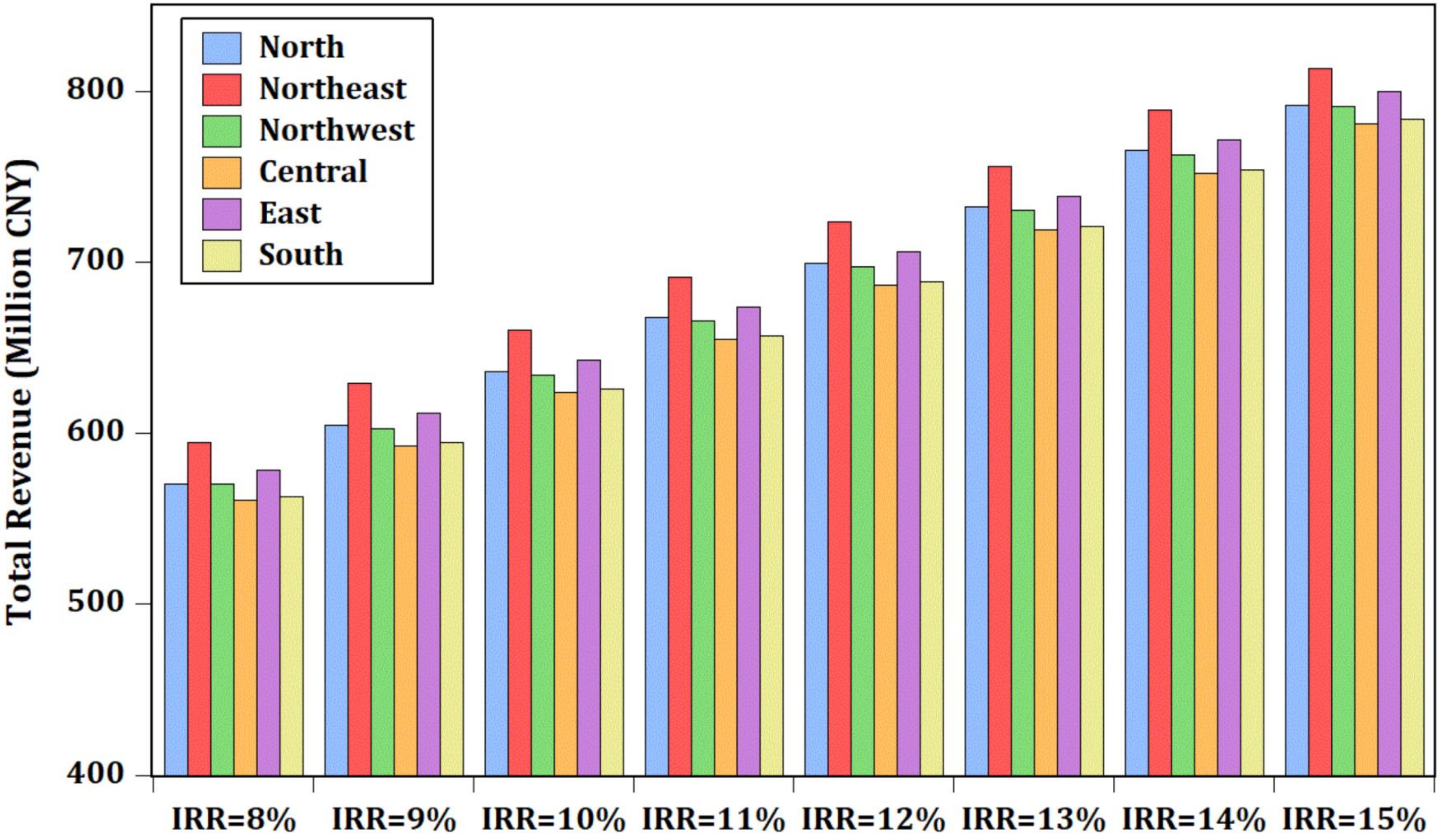

Figure 4.6 Estimated NPV of wind farm project value under different value of IRR

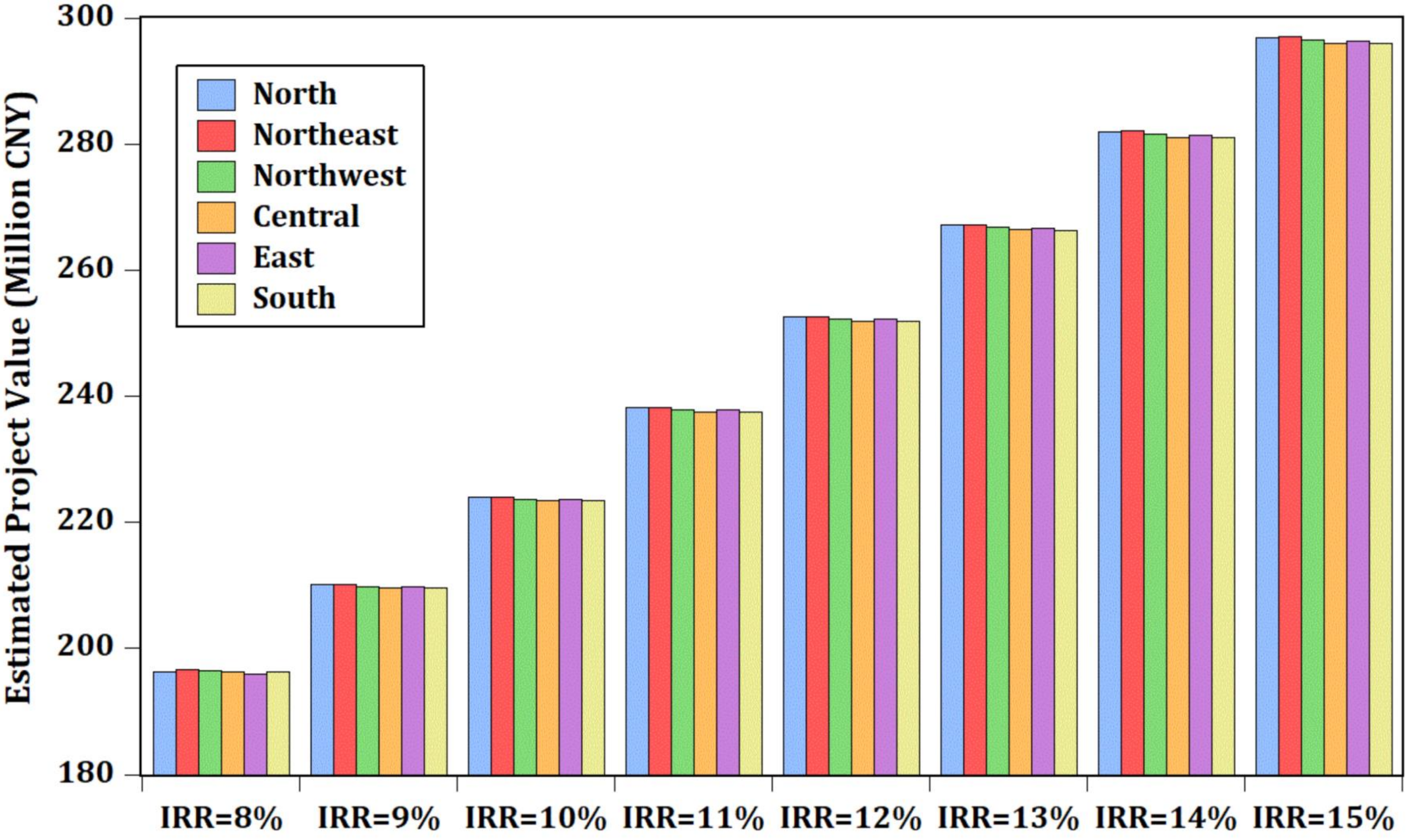

Figure 4.7 Estimated annual grid-connected wind power generation and polluting emission reduction

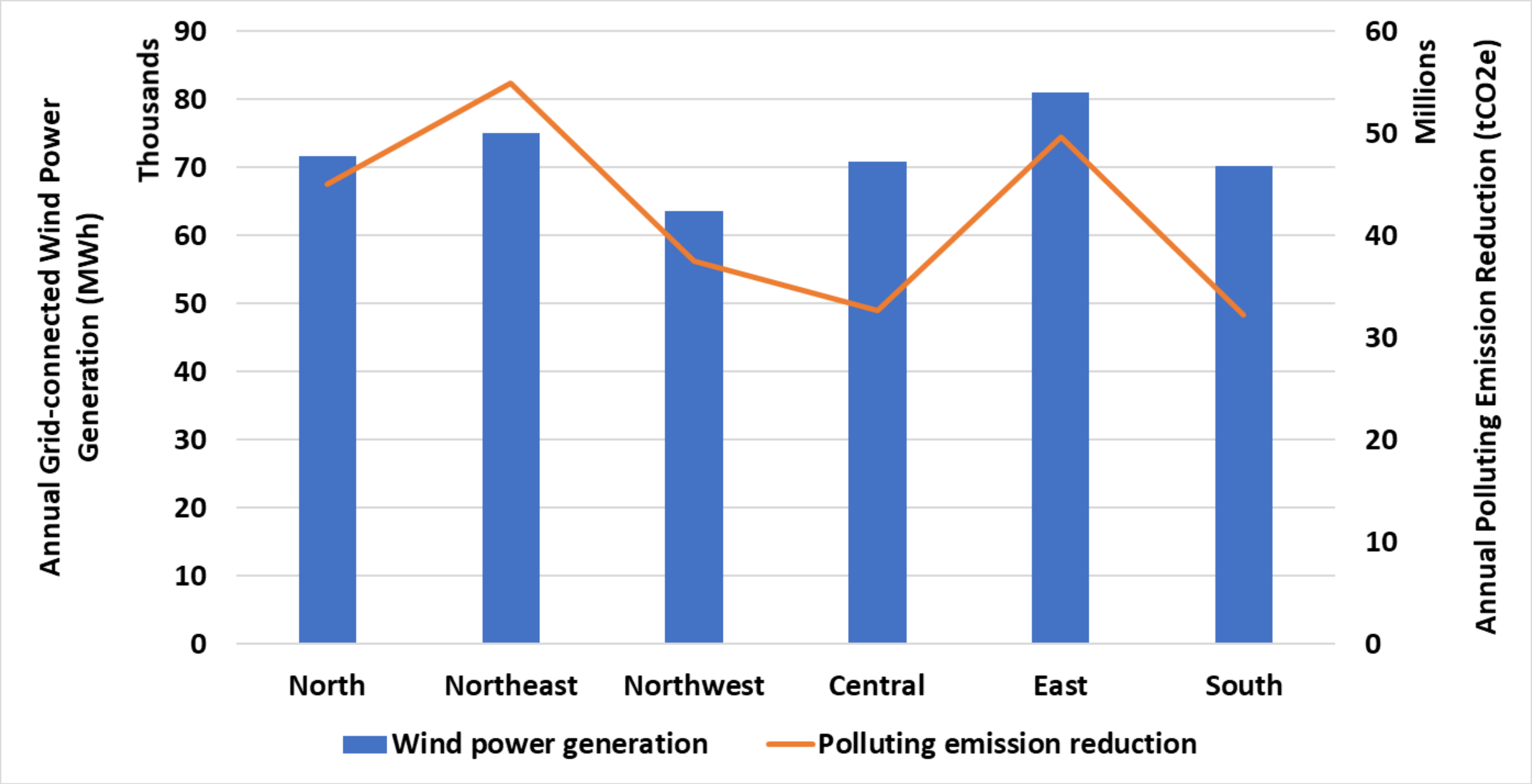

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Figure 4.8 Percentage share of regional electricity consumption and cumulative wind power installed capacity to national total amount.

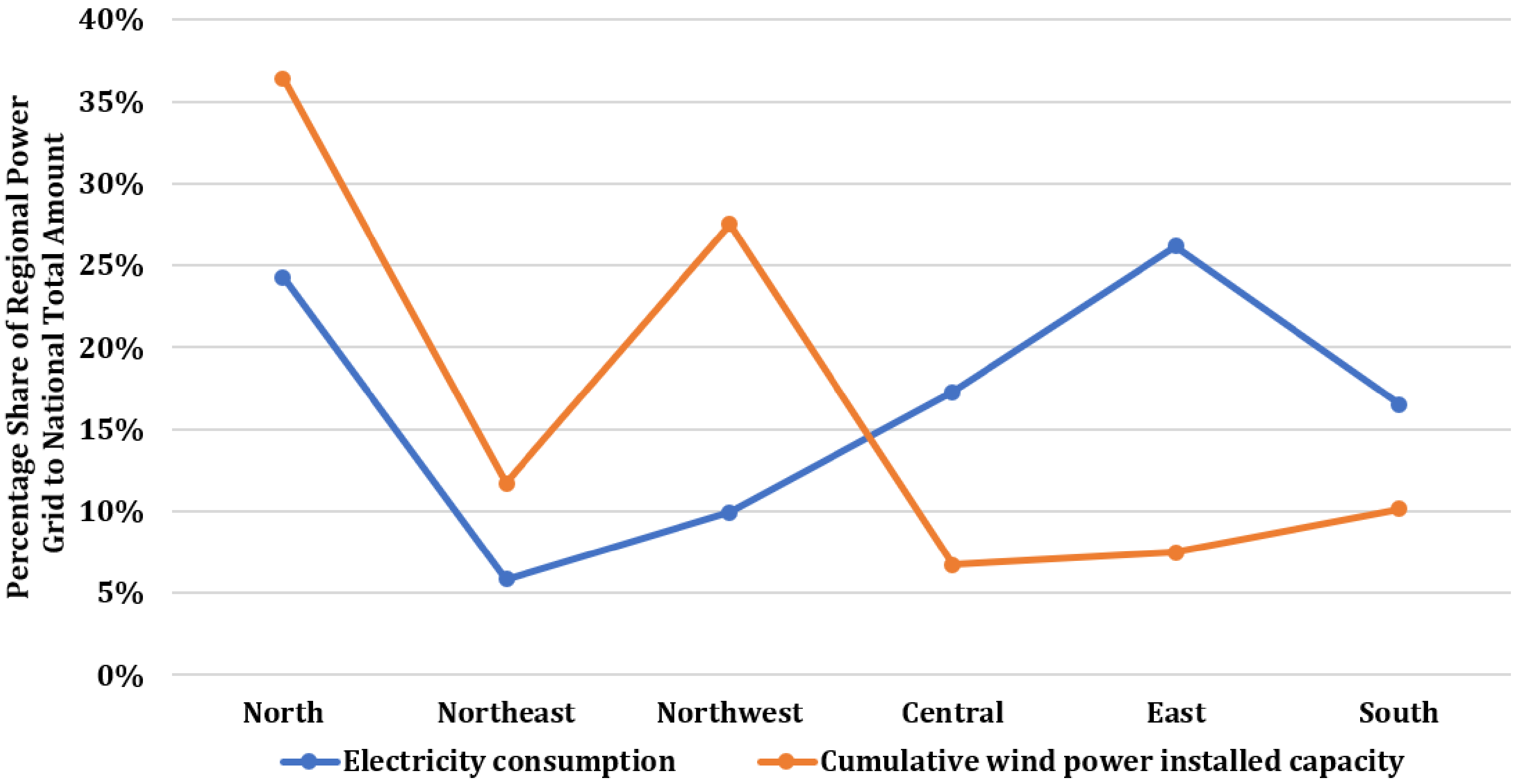

Figure 4.9 Estimated LCOE of Wind Power in Different Regional Power Grids

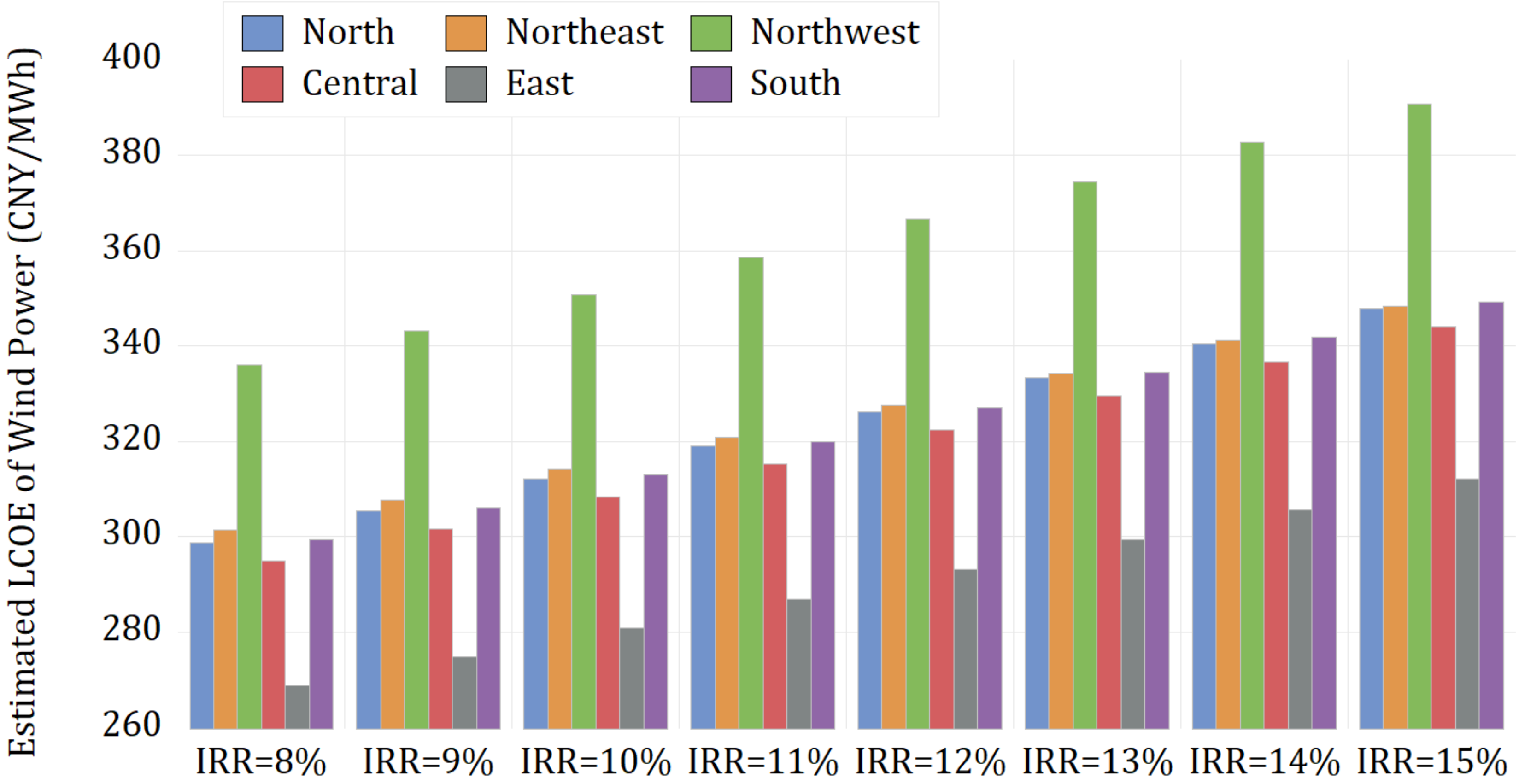

Figure 4.10 Sensitivity Analysis (Under the circumstance of IRR=8%)

Change of Parameters		**North**					**Northeast**					**Northwest**				
		IRR	**ROI**	**Chang of Project Value**	**Chang of Total Expenditure**	**Payback Period (Years)**	**IRR**	**ROI**	**Chang of Project Value**	**Chang of Total Expenditure**	**Payback Period (Years)**	**IRR**	**ROI**	**Chang of Project Value**	**Chang of Total Expenditure**	**Payback Period (Years)**
Discount Rate	-10%	8%	10%	3.6%	0.0%	9	8%	11%	3.6%	0.0%	9	8%	11%	3.7%	0.0%	9
	-5%	8%	10%	1.6%	0.0%	9	8%	10%	1.6%	0.0%	10	8%	10%	1.7%	0.0%	9
	0	8%	9%	0.0%	0.0%	9	8%	9%	0.0%	0.0%	9	8%	9%	0.0%	0.0%	9
	5%	8%	8%	-2.2%	0.0%	9	8%	8%	-2.2%	0.0%	9	8%	8%	-2.1%	0.0%	9
	10%	8%	7%	-4.0%	0.0%	9	8%	7%	-4.0%	0.0%	9	8%	8%	-3.9%	0.0%	9
Upfront Cost	-10%	10%	13%	0.0%	-3.7%	8	10%	13%	-0.3%	-3.5%	8	10%	13%	-0.2%	-3.7%	8
	-5%	9%	11%	0.0%	-1.8%	8.5	9%	11%	-0.3%	-1.7%	8.5	9%	11%	-0.2%	-1.8%	8.5
	0	8%	9%	0.0%	0.0%	9	8%	9%	0.0%	0.0%	9	8%	9%	0.0%	0.0%	9
	5%	7%	7%	0.0%	1.8%	9.5	7%	7%	-0.3%	1.7%	9.5	7%	7%	-0.2%	1.8%	9.5
	10%	7%	5%	0.0%	3.7%	10	7%	5%	-0.3%	3.5%	10	7%	5%	-0.2%	3.7%	10
On-grid Power Generation	-10%	6%	4%	-11.6%	-3.6%	10	6%	4%	-10.8%	-3.2%	10	6%	5%	-10.5%	-3.3%	10
	-5%	7%	7%	-6.0%	-1.8%	9.5	7%	7%	-5.6%	-1.6%	9.5	7%	7%	-5.4%	-1.7%	9.5
	0	8%	9%	0.0%	0.0%	9	8%	9%	0.0%	0.0%	9	8%	9%	0.0%	0.0%	9
	5%	9%	12%	5.3%	1.8%	8.5	9%	11%	4.9%	1.6%	8.5	9%	11%	4.9%	1.7%	8.5
	10%	10%	14%	11.0%	3.6%	8	10%	13%	10.1%	3.2%	8	10%	14%	10.1%	3.3%	8
Carbon Trading Price (Scenario I)	-10%	8%	9%	-1.3%	-0.3%	9	8%	8%	-1.4%	-0.3%	9	8%	9%	-0.9%	-0.2%	9
	-5%	8%	9%	-0.8%	-0.2%	9	8%	9%	-0.9%	-0.2%	9	8%	9%	-0.6%	-0.1%	9
	0	8%	9%	0.0%	0.0%	9	8%	9%	0.0%	0.0%	9	8%	9%	0.0%	0.0%	9
	5%	8%	9%	0.2%	0.2%	9	8%	9%	0.2%	0.2%	9	8%	9%	0.1%	0.1%	9
	10%	8%	10%	0.7%	0.3%	9.5	8%	9%	0.7%	0.3%	9.5	8%	10%	0.5%	0.2%	9.5
Carbon Trading Price (Scenario II)	-10%	8%	9%	-1.0%	4.0%	9	8%	8%	-1.1%	3.8%	9	8%	9%	-0.7%	4.0%	9
	-5%	8%	9%	-0.5%	4.1%	9	8%	9%	-0.5%	4.0%	9	8%	9%	-0.3%	4.1%	9
	0	8%	9%	0.0%	0.0%	9	8%	9%	0.0%	0.0%	9	8%	9%		0.0%	9
	5%	8%	10%	0.6%	4.4%	8	8%	9%	0.5%	4.3%	8	8%	10%	0.4%	4.3%	8
	10%	8%	10%	0.9%	4.6%	8	8%	9%	1.1%	4.5%	8	8%	10%	0.8%	4.5%	8
Unit O&M Cost	-10%	8%	11%	2.8%	-2.1%	8.5	9%	11%	3.2%	-2.4%	8.5	8%	11%	2.8%	-2.1%	8.5
	-5%	8%	10%	1.2%	-1.1%	9	8%	10%	1.4%	-1.2%	9	8%	10%	1.3%	-1.1%	9
	0	8%	9%	0.0%	0.0%	9	8%	9%	0.0%	0.0%	9	8%	9%	0.0%	0.0%	9
	5%	8%	8%	-1.8%	1.1%	9	8%	8%	-2.1%	1.2%	9	8%	8%	-1.7%	1.1%	9
	10%	8%	8%	-3.4%	2.1%	10	7%	7%	-3.9%	2.4%	10	8%	8%	-3.2%	2.1%	10

Change of Parameters		Central					East					South				
		IRR	ROI	Chang of Project Value	Chang of Total Expenditure	Payback Period (Years)	IRR	ROI	Chang of Project Value	Chang of Total Expenditure	Payback Period (Years)	IRR	ROI	Chang of Project Value	Chang of Total Expenditure	Payback Period (Years)
Discount Rate	-10%	8.0%	11.0%	3.8%	0.0%	9	8.0%	11.0%	3.8%	0.0%	9	8.0%	11.0%	3.8%	0.0%	9
	-5%	8.0%	10.0%	1.8%	0.0%	9	8.0%	10.0%	1.8%	0.0%	9	8.0%	10.0%	1.8%	0.0%	9
	0	8.0%	9.0%	0.0%	0.0%	9	8.0%	9.0%	0.0%	0.0%	9	8.0%	9.0%	0.0%	0.0%	9
	5%	8.0%	9.0%	-2.0%	0.0%	9	8.0%	8.0%	-2.0%	0.0%	9	8.0%	9.0%	-2.0%	0.0%	9
	10%	8.0%	8.0%	-3.8%	0.0%	9	8.0%	7.0%	-3.8%	0.0%	9	8.0%	8.0%	-3.8%	0.0%	9
Upfront Cost	-10%	10.0%	14.0%	-0.2%	-3.7%	8	10.0%	13.0%	-0.1%	-3.6%	8	10.0%	14.0%	-0.1%	-3.7%	8
	-5%	9.0%	12.0%	-0.2%	-1.9%	8.5	9.0%	11.0%	-0.1%	-1.8%	8.5	9.0%	12.0%	-0.1%	-1.9%	8.5
	0	8.0%	9.0%	0.0%	0.0%	9	8.0%	9.0%	0.0%	0.0%	9	8.0%	9.0%	0.0%	0.0%	9
	5%	7.0%	7.0%	-0.2%	1.9%	9.5	7.0%	7.0%	-0.1%	1.8%	9.5	7.0%	7.0%	-0.1%	1.9%	9.5
	10%	7.0%	5.0%	-0.2%	3.7%	10	7.0%	5.0%	-0.1%	3.6%	10	7.0%	5.0%	-0.1%	3.7%	10
On-grid Power Generation	-10%	6.0%	4.0%	-12.5%	-4.1%	10	6.0%	4.0%	-12.7%	-4.0%	10	6.0%	4.0%	-12.2%	-4.0%	10
	-5%	7.0%	7.0%	-6.3%	-2.0%	9.5	7.0%	6.0%	-6.4%	-2.0%	9.5	7.0%	7.0%	-6.2%	-2.0%	9.5
	0	8.0%	9.0%	0.0%	0.0%	9	8.0%	9.0%	0.0%	0.0%	9	8.0%	9.0%	0.0%	0.0%	9
	5%	9.0%	12.0%	6.0%	2.0%	8.5	9.0%	12.0%	6.1%	2.0%	8.5	9.0%	12.0%	5.9%	2.0%	8.5
	10%	10.0%	15.0%	12.2%	4.1%	8	10.0%	14.0%	12.4%	4.0%	8	10.0%	15.0%	12.0%	4.0%	8
Carbon Trading Price (Scenario I)	-10%	8.0%	9.0%	-0.6%	-0.1%	9	8.0%	9.0%	-0.8%	-0.2%	9	8.0%	9.0%	-0.6%	-0.1%	9
	-5%	8.0%	9.0%	-0.4%	-0.1%	9	8.0%	9.0%	-0.5%	-0.1%	9	8.0%	9.0%	-0.4%	-0.1%	9
	0	8.0%	9.0%	0.0%	0.0%	9	8.0%	9.0%	0.0%	0.0%	9	8.0%	9.0%	0.0%	0.0%	9
	5%	8.0%	10.0%	0.1%	0.1%	9	8.0%	9.0%	0.2%	0.1%	9	8.0%	10.0%	0.1%	0.1%	9
	10%	8.0%	10.0%	0.3%	0.1%	9.5	8.0%	9.0%	-0.7%	0.2%	9.5	8.0%	10.0%	0.3%	0.1%	9.5
Carbon Trading Price (Scenario II)	-10%	8.0%	9.0%	-0.5%	4.1%	9	8.0%	9.0%	-0.4%	4.0%	9	8.0%	9.0%	-0.4%	4.1%	9
	-5%	8.0%	9.0%	-0.2%	4.2%	9	8.0%	9.0%	4.7%	4.1%	9	8.0%	9.0%	-0.2%	4.2%	9
	0	8.0%	10.0%	0.0%	0.0%	9	8.0%	9.0%	0.0%	0.0%	9	8.0%	9.0%	0.0%	0.0%	9
	5%	8.0%	10.0%	0.2%	4.3%	8	8.0%	9.0%	0.4%	4.4%	8	8.0%	10.0%	0.2%	4.3%	8
	10%	8.0%	10.0%	0.3%	4.4%	8	8.0%	9.0%	0.7%	4.5%	8	8.0%	10.0%	0.5%	4.4%	8
Unit O&M Cost	-10%	8.0%	11.0%	2.7%	-2.0%	8.5	8.0%	11.0%	3.1%	-2.2%	8.5	8.0%	11.0%	2.7%	-2.1%	8.5
	-5%	8.0%	10.0%	1.3%	-1.0%	9	8.0%	10.0%	1.5%	-1.1%	9	8.0%	10.0%	1.3%	-1.0%	9
	0	8.0%	9.0%	0.0%	0.0%	9	8.0%	9.0%	0.0%	0.0%	9	8.0%	9.0%	0.0%	0.0%	9
	5%	8.0%	9.0%	-1.6%	1.0%	9	8.0%	8.0%	-1.8%	1.1%	9	8.0%	9.0%	-1.6%	1.0%	9
	10%	8.0%	8.0%	-3.0%	2.0%	10	7.0%	7.0%	-3.4%	2.2%	10	8.0%	8.0%	-3.0%	2.1%	10

4.4. Sensitivity Analysis

This study has conducted the sensitivity analysis under the condition of IRR=8% and the results are presented in Fig. 4.10. Discount rate, upfront cost, on-grid power generation, carbon trading price (Scenario I), carbon trading price (Scenario II) and unit O&M cost are assessed in the sensitivity analysis because they are dynamic parameters. The changes of these parameters are set as decreased by 5%, decreased by 10%, increased by 5% and increased by 0%, respectively. Correspondingly, the change of IRR, Return on Investment (ROI)[11], project value, total expenditure and payback period are calculated. IRR, ROI and payback period helps the investors to understand the return of the investment in diverse ways.

It is found that the IRR and payback period are mainly influenced by upfront cost and on-grid power generation, and the values of IRR after adjusting the value of upfront cost and on-grid power generation vary from 6% to 10%, while payback period varies from 8 years to 10 years. ROI is mainly influenced by discount rate, upfront cost and on-grid power generation, and the values of ROI after adjusting these three parameters vary from 7% to 11%, 5% to 14% and 4% to 15%, respectively. The change of project value is mainly influenced by on-grid power generation and varies from -12.7% to 12.4%, slightly influenced by discount rate and varies from -4% to 3.8%. The change of total expenditure is mainly influenced by upfront cost and on-grid power generation, and the changes of total expenditure after adjusting these two parameters vary from -3.8% to 3.8% and -4.1% to 4.1%, respectively.

The sensitivity analysis reveals that the most sensitive parameters in the model are on-grid power generation and upfront cost. The investor's profit will be increased drastically if the amount of the on-grid

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[11] ROI refers to the ratio of the project value to the total expenditure, and it can be considered as a simplified approximation for IRR (Aho and Virtanen, 1983). It is presented in the sensitivity analysis because this section intends to show the return of the investment in diverse ways.

power generation is increased, and the investor's expenditure will be decreased if the upfront cost is reduced. Therefore, the government and the grid companies are expected to play crucial roles to improve the investment environment. The government could impulse development of wind power technology to decrease the upfront cost by investors. The grid companies could reallocate the wind power grid connection quota to alleviate the wind curtailment problem, and improve the on-grid wind power connection.

4.5. Chapter Conclusion

This study has proposed a new wind power FIT benchmark price mechanism by applying the NPV method and RO method to optimize the FIT price in accordance to a baseline of IRR for enterprises fall in between 8% to 15%. The new wind power FIT benchmark price mechanism refers to a differentiated benchmark price mechanism based on six regional power grids in China, which is strongly recommended to substitute the current category-based mechanism. The NPV is calculated based on the cash flow of profit from selling electricity to the power grids, profit from receiving compensation due to systematic failure that should not be held accountable by wind farm investors, profit from participating in carbon trading certification mechanism, expenditure on operation and maintenance cost, as well as expenditure on tax payment. The RO method is employed to calculate the enterprises' managerial flexibility and uncertainty, which is regarded as a stochastic loss added to the fixed upfront payment. The RO method synthesizes the market capitalization and stock daily return of five leading wind farm manufacturers and five leading domestic wind power generators in China, and then produces 1002 asset portfolios by simulating all possible combinations among these ten enterprises. The value of RO represents the risks related to enterprises' right to postpone the investment. The results are comprehensively interpreted in Section 3.

CHAPTER FIVE

Conclusion

5.1. Policy Implications from Reviewing the Wind Power Development in China

This thesis has comprehensively depicted the evolution and implementation of onshore and offshore wind energy in China during 2005 to 2016 under the wind energy policies, especially the Feed-in-tariff policy. The cumulative and newly added wind installed capacity, wind power connected to grid and capacity factor, abandoned wind power and wind power curtailment rate are analysed based on provincial data. The review fills the research gap during the late-12th FYP and the early-13th FYP. The structural change of wind turbine manufacturers in domestic market is also depicted under the effect of tax reduction policy.

Although prominent progress has been made in the past ten years regarding the wind installed capacity and the localization of domestic manufacturers, low wind farm capacity factor and severe wind curtailment rate problems are two salient threats for the future wind power accommodation. To address these two threats, the deficiencies in the roles of actors that are participating in the wind power supply chain are discussed. Due to the uniqueness of China's decision-making mechanism, the local Government plays a crucial role to solve the problems. Local governments, grid companies, power generation enterprises, manufacturers and R&D parties are also responsible to alter the situation. The inconsistency of wind power generation and grid planning, low offshore FIT price and cost sharing incentives and low priority of energy management authorities are problems from the central government's perspective. Besides, the ambiguous position of local government causes the exceeding development of local wind energy and unstructured grid planning with local grid companies. In addition, lack of technology improvement and insufficient support for R&D impede industries' interests in discovering high quality wind turbines. Difficulties in wind power integration and lagged construction of transmission lines make the accommodation of wind power rather in dilemma.

This thesis suggests the following aspects to address the deficiencies:

(1) A more sophisticated, flexible, effective and responsive policy mechanism should be designed for a safer and more adaptive wind power development. Such regulatory mechanisms require a stronger regulatory framework and improved communication channels between central and sub-national governments, with core tasks being well-specified and effectively allocated between the incumbent NDRC and the SERC, as well as between central and local governments. The most crucial functions of the regulatory mechanism should ensure fair competition between SOEs and IPPs, and promote efficient competition through which price induces profit incentives and more predictable market growth for the domestic wind energy industry.

(2) The power dispatch policy should be redesigned and strengthened. It is suggested that the wind power should be mandatorily dispatched to the grid with minimum amount of curtailment, and the dispatch of coal-fired power should be on the energy-efficient-basis rather than an "equal share" approach. The energy-efficient-based pattern requires the dispatch of coal-fired power take the priority if it has higher thermal efficiency (Kahrl, Williams, & Hu, 2013; Wei et al., 2018). However, this transition will induce tension between Central government and local governments due to conflicts and imbalance when reallocating power resources. Therefore, it is recommended that compensation mechanism should be introduced to make up for the stakeholders' loss, and the government-generator-grid company should make the dispatch process transparent to the public.

(3) A broader and high-level collaboration platform should be built for developing research frontier among research institutes, energy organizations, and international research committees. The cultivation of research personnel should be differentiated from enterprise's normal research activity. More qualified research institutes should be established to educate and cultivate cutting-edge technology talents, and encourage more researchers to engage in comprehensive and elaborate energy projects with long-term research cycle. Besides, it is vital to integrate various innovative resources, with key R&D projects as a link, to share multidisciplinary information, R&D facilities, and science and technology achievements.

(4) A market-independent wind power environment should be established. Nowadays, the localization of the Chinese wind energy industry has achieved a prosperous scene. Since a power company usually prefers to diversify its business, the boundary between manufacturers and generators has gradually vanished. Thus, it is a good opportunity for the government to liberalize the power selling market. A market-independent wind power environment allows various wind power generators and manufacturers to easily enter the market and sells the electricity in a form of retail. This kind of market also allows end-users to choose their preferable retailers, which will make the power market more competitive. However, this is a tough step for China as a highly centralised entity, but it is foreseeable to suggest the government to commission a liberalised power market as a trial in some regions.

5.2. Policy Implications from Evaluating the Current Wind FIT Policy

Currently, the wind FIT policy in China is classified into four categories based on the distribution of wind resource, and this policy design is proved as effective to promote the rapid development of wind power generation. However, the rapid development phenomenon is seemed to be a feature of renewable energy development at the starting stage in China, problems related to severe wind curtailment and regional wind power grid connection are exposed along with the wind power development, and these problems have revealed that after the starting stage, the current FIT wind policy is no longer appropriate and optimal for the maturing stage without taking regional differences into account. Thus, the most significant contribution of this thesis is to figure out the determinants on effectively improving wind installed capacity by regional grids. The regional differences are reflected by taking the amount of coal consumption, GDP per capita, electricity price and electricity intensity as control variables into consideration, and the current wind FIT policy should be reformed, while a more adaptive, sophisticated and flexible wind FIT policy is necessary to be proposed to fit with the regional features and differences.

First, the design elements of wind FIT policy should not be constrained to the same parameters at national-level, regional differences should be included. To reform wind FIT policy, it is suggested to establish a tailor-made policy mechanism to fit with the using pattern of coal or other electricity generation energies, the development degree of economy, the electricity price in a specific market and the energy efficiency of an economy. The reformed wind FIT policy is therefore recommended to be segmented into six sub-policies particularly aiming to North China grid, Northeast China grid, Northwest China grid, South China grid, East China grid and Central China grid. For instance, for the North China grid, the crucial determinants of promoting cumulative installed wind capacity are regional coal consumption, regional GDP per capita and regional electricity intensity, thus the reformed FIT price especially for North China grid should consider neutralizing these three elements together with the wind resource potential.

Besides, the optimization of FIT price need to be precisely adjusted by referring to different payoff structures. The structures are not restrained to the form of providing a fixed price per unit electricity produced by wind energy, other payoff structures such as a guaranteed minimum price plus a portion of market upside or a certain premium based on the top of the electricity spot price are suggested by Devine et al. (2017) and Kim and Lee (2012). However, these two works are formulated for improving and optimizing the FIT design in the Irish context and a generalized world context, so the application of other forms of FIT price mechanism in the Chinese context should be carefully studied and investigated to figure out a most appropriate approach.

5.3. Policy Implications from Proposing a Regional-power-grid-based Wind FIT Policy

This study contributes to the realignment of regional wind power FIT benchmark price level, which provides insights regarding the *Notice on work related to wind power and photovoltaic power generation connected to grid without subsidy*. The policy implications are summarized as follows:

(1) The open of China's nationwide carbon trading scheme and the implementation of renewable energy compensation are considered in the model. Whether the carbon trading mechanism is operated under a relatively liberalized electricity market (Scenario I) or under government's strict regulation (Scenario II), the proposed wind power FIT benchmark price level has provided the policymaker some comprehensive and systematic foresights by categorizing the IRR in different regional power grids.

(2) The risks and concerns of low IRR by the investors are eliminated and the investors are released from struggling against their social accountability by the RPS scheme and uncertainties brought by the systematic fault.

(3) According to the sensitivity analysis, the most sensitive parameters in the model are the upfront cost and the grid-connect wind power generation. Therefore, improving technological development and restructuring grid planning to decrease the upfront cost or alleviate wind curtailment problem are the most efficient way to improve the investment environment.

(4) The redistribution of FIT subsidies is recommended. The proposed wind power FIT benchmark price level has reached a balance of regional differences, so the current FIT price should be realigned and redistributed.

The estimated Levelized Cost of Electricity (LCOE) of wind power in different regional power grids indicates that the wind power production in East China grid is the most cost-effective, whereas in Northwest is the least cost-effective. Therefore, stimulating or inhibiting the investment in different regional power grids should be adjusted.

5.4. Research Limitations and Future Work

The research limitations and future work of this thesis is concluded as follows:

(1) This thesis has considered the national carbon trading scheme when constructing the design model, the carbon trading prices is determined whether constant or increasing in the first several years. Nevertheless, regardless of the which trend the price will turn to be, the start point of the price is established based on the average carbon trading price value of the seven pilot cities, which is a generalized fixed value of each year. However, in reality, the current carbon trading price in pilot

cities are drastically fluctuated on a daily-basis, so the value used in the model is a simplified average value which does not consider the daily change or the seasonal change.

(2) The future work is suggested to focus on monitoring the performance of economy, technology and related renewable energy policy, pay attention to any change of the exogeneous variables and endogenous variables that may affect the calibration of the model. The proposed model can be modified if needed.

(3) This policy design framework and proposed model could also be expanded to other applications of renewable power, i.e., subsidy policies of offshore wind power and solar power.

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Appendices

A. Classification of regional power grids and wind resource areas.

The 31 provinces, autonomous regions and municipalities are divided into 6 clusters according to the grid power connection zone planning. China has two state-owned grid companies, namely State Grid Corporation of China (SGCC) and China Southern Power Grid Corporation (CSG), respectively. SGCC provides power for 26 provinces/autonomous regions/municipalities and includes **North China Grid** (Beijing, Tianjin, Hebei, Shanxi, West Inner Mongolia and Shandong), **Northeast China Grid** (East Inner Mongolia, Liaoning, Jilin and Heilongjiang), **Central China Grid** (Henan, Hubei, Hunan, Jiangxi, Sichuan and Chongqing), **East China Grid** (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian) and **Northwest China Grid** (Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Tibet). The CSG covers the remaining 5 provinces (Guangdong, Guangxi, Yunnan, Hainan and Guizhou).

Figure A.I Classification of six regional power grids in China

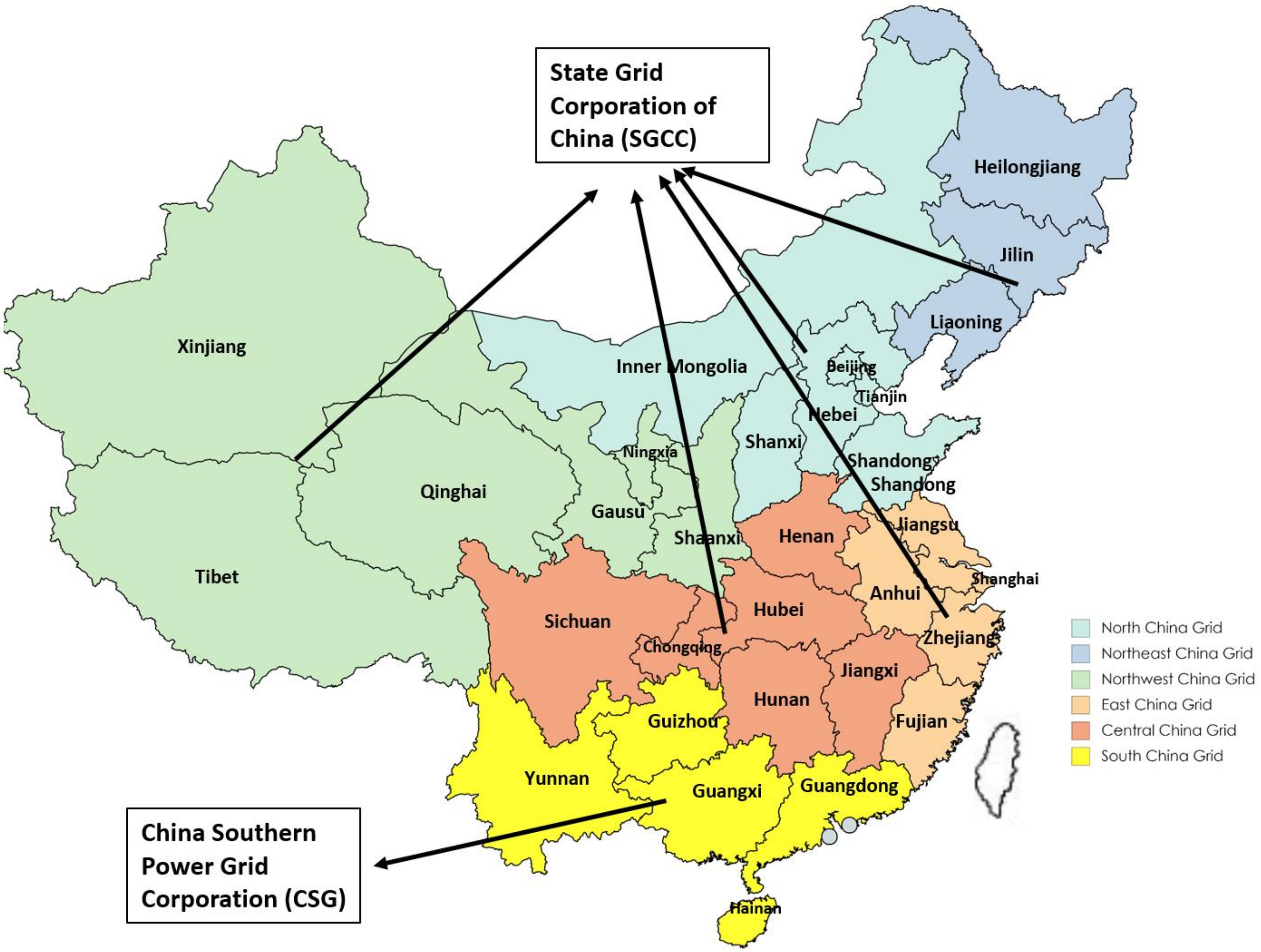


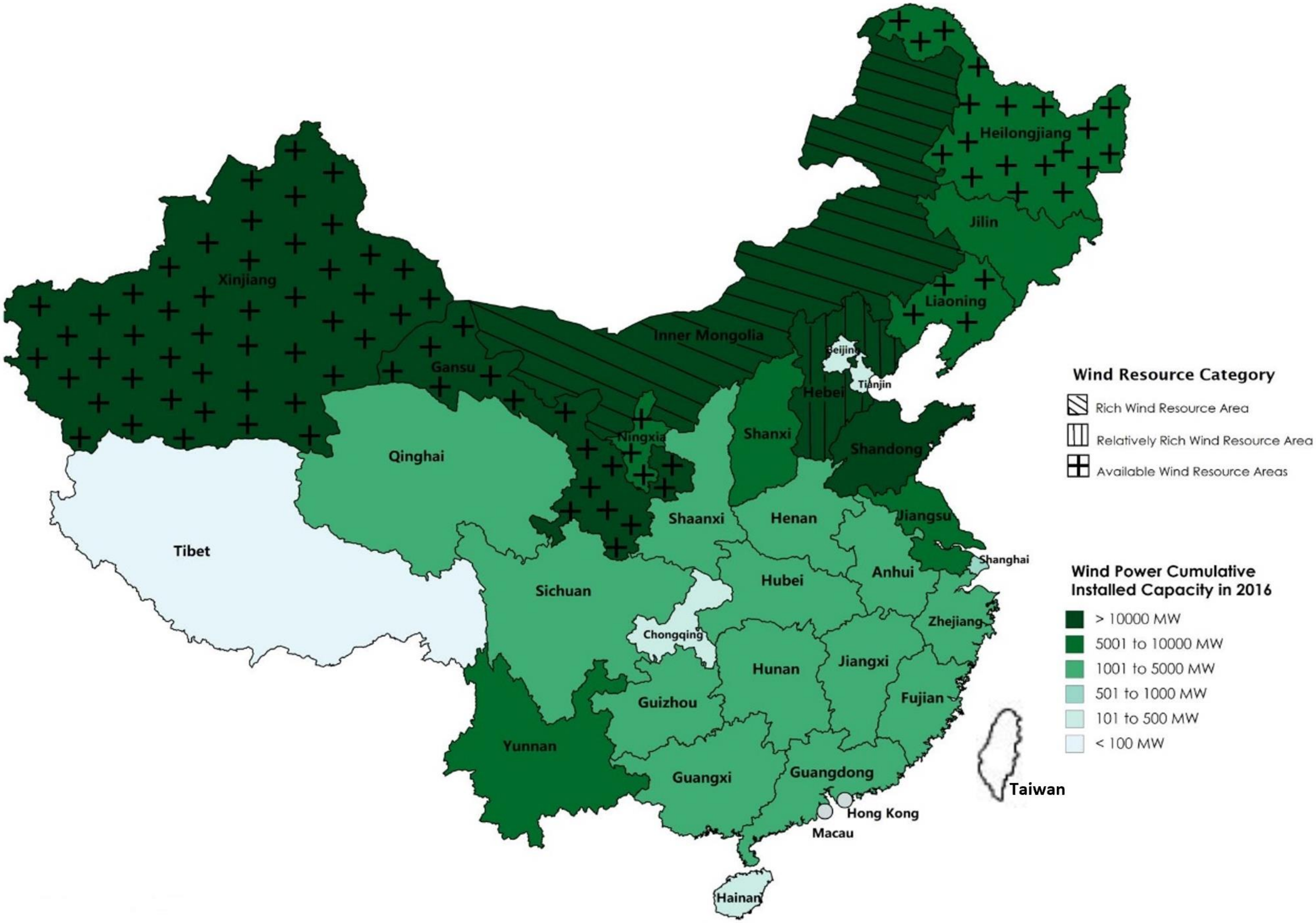
Table A.1 Provinces/ Autonomous regions/ Municipalities included in four categories of wind resources (NDRC).

Administrative areas included (Hu et al. 2013)
Category I: Inner Mongolia autonomous region except: Chifeng, Tongliao, Xing'anmeng, Hulunbeier; **Xinjiang uygur autonomous region**: Urumqi, Yili, Karamay, Shihezi
Category II: Hebei province: Zhangjiakou, Chengde; **Inner Mongolia autonomous region:** Chifeng, Tongliao, Xing'anmeng, Hulunbeier; **Gansu province**: Zhangye, Jiayuguan, Jiuquan
Category III: Jilin province: Baicheng, Songyuan; **Heilongjiang province**: Jixi, Shuangyashan, Qitaihe, Suihua, Yichun, Daxinganling region, **Gansu province except:** Zhangye, Jiayuguan, Jiuquan, **Xinjiang autonomous region except**: Urumqi, Yili, Changji, Karamay, Shihezi, **Ningxia Hui autonomous region**
Category IV: Other parts of China not mentioned above

Table A.2 Classification of four wind resource areas

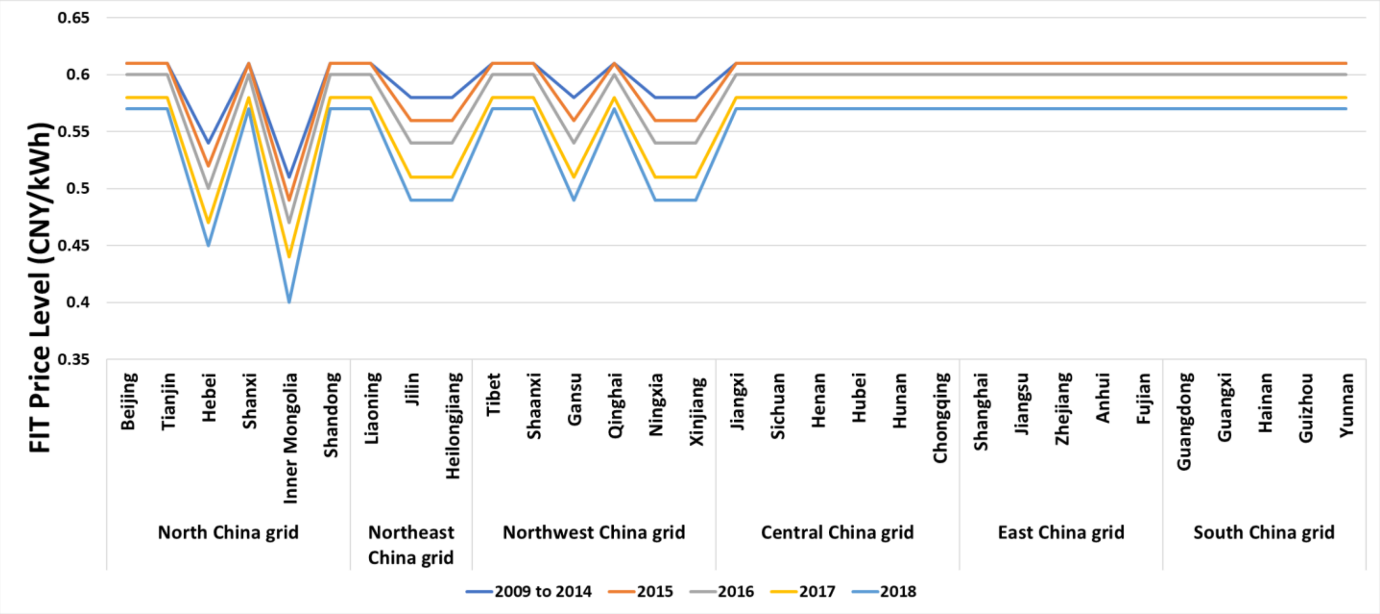
Category	Annual average effective wind energy density (D, W/m^2)	annual cumulative hours (H) of wind speed of 3-20 m/s	Occupation of national area
I - Rich	$D > 200$	$H > 5000$	8%
II – Relatively rich	$150 < D < 200$	$3000 < H < 5000$	18%
III - Available	$50 < D < 150$	$2000 < H 3000$	24%
IV - Poor	$D < 50$	$H < 2000$	50%

Figure A.2 Wind resource classification and cumulative installed wind power capacity in 2016.



B. FIT Benchmark Price Level

Figure B.1 Current wind power FIT price level



C. Supplementary Material for Real Option Method

Table C.1 Code of 10 enterprises

	Full Name	Code
Manufacturer	Xinjiang Goldwind Science & Technology Co., Ltd	2208.HK
	Sinovel Wind Group Co., Ltd.	601558.SS
	Dongfang Electric Corporation Limited	1072.HK
	Zhuzhou CRRC Times Electric Co., Ltd.	3898.HK
	CGN Power Co., Ltd	1816.HK
Generator	Huaneng Power International, Inc.	HNP
	Datang International Power Generation Co., Ltd.	0991.HK
	SDIC Power Holdings CO., LTD.	600886.SS
	Huadian Power International Corporation Limited	1071.HK
	China Resources Power Holdings Company Limited	0836.HK

Table C.2 Descriptive statistics of stock daily return in 10 firms

Code	HNP	0991.HK	600886.SS	1071.HK	0836.HK
Mean	-7.06E-05	-0.00138	0.000862	0.001818	0.00099
Median	-0.001201	-0.005038	-0.001301	0.00342	-0.000649
Maximum	0.048341	0.043478	0.038136	0.076087	0.056277
Minimum	-0.064502	-0.040404	-0.036458	-0.061856	-0.030211
Std. Dev.	0.019297	0.016383	0.014556	0.027393	0.01692
Skewness	-0.229209	0.256181	-0.038769	0.144004	0.488794
Kurtosis	3.873951	2.995711	3.466009	2.951574	3.328049
Jarque-Bera	3.652265	0.984498	0.836911	0.319853	3.987357
Probability	0.161035	0.61125	0.658062	0.852206	0.136194
Sum	-0.006356	-0.124196	0.077541	0.163657	0.089088
Sum Sq. Dev.	0.033141	0.023888	0.018856	0.066782	0.02548
Observations	90	90	90	90	90
Code	**2208.HK**	**601558.SS**	**1072.HK**	**3898.HK**	**1816.HK**
Mean	-0.002845	0.000705	0.001337	0.000687	-0.000869
Median	-0.006351	0.008403	-0.002232	-0.003561	-0.004914
Maximum	0.119829	0.066038	0.049875	0.051059	0.032967
Minimum	-0.105951	-0.054054	-0.062069	-0.042506	-0.045
Std. Dev.	0.035458	0.020693	0.022094	0.018676	0.013989
Skewness	0.375927	0.305314	0.002183	0.362375	-0.238175
Kurtosis	4.19873	3.745883	3.02367	2.77562	3.519309
Jarque-Bera	7.508392	3.484535	0.002172	2.158536	1.862216
Probability	0.023419	0.175123	0.998914	0.339844	0.394117
Sum	-0.25602	0.063438	0.12034	0.061818	-0.078231
Sum Sq. Dev.	0.1119	0.038111	0.043443	0.031044	0.017418
Observations	90	90	90	90	90