MSc Program
Renewable Energy Systems

Renewable Energy in China: Status and Future Prospects

A Master's Thesis submitted for the degree of
"Master of Science"

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Affidavit

I, **Christhian Rengifo**, hereby declare

1. that I am the sole author of the present Master Thesis, "RENEWABLE ENERGY IN CHINA: STATUS AND FUTURE PROSPECTS", 96 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

The objective of this work is to analyse the current status of the Chinese renewable energy program (wind power and solar PV) and outline its future prospects. In this context, one particular endeavour of this work has been to discuss China not only at the macro level (i.e. China as a single unit), but also to discuss the different financial and technical realities of the wind and solar PV sectors at the provincial level. This work will use a combination of quantitative and qualitative data for the analysis of the country's renewable energy program. The quantitative analysis will cover areas such as power demand/supply dynamics, electricity capacity and production, Feed-in Tariff costs, and other factors regarding the economics of renewable energy. The qualitative analysis mainly covers the areas related to environmental and energy policies, including the latest reforms of the power sector. This work has been able to identify the unique features of the Chinese renewable energy program and further research should be undertaken in order improve the understanding of renewable energy development in China and the complexity of its national and provincial system for developing wind and solar PV.

In the last ten years, China has made major progress in the deployment of wind power and solar PV capacity and it will likely meet or surpass its 2020 targets for these power sources. There are, however, several challenges ahead for the deployment of these electricity sources. China is not only planning to increase renewable energy capacity to its electricity mix by 2020 and beyond, but it is also expanding the capacity of nuclear, hydro, natural gas, and – to a lesser extend – coal. As China's is experiencing power overcapacity, the constant expansion of electricity production does not seem to be the best way forwards for the country. The government is, nevertheless, trying to address the overcapacity issue and other related challenges and has introduced several pieces of legislation to reform the Chinese electricity market. Many of these reforms have just started to be implemented or will start soon. It is therefore too early to predict how they will affect the electricity market in general and the wind power and solar PV markets in particular. What is clear though is that the Chinese government has taken the policy decision to move away from coal and deploy sources with lower CO_2 emissions.

1. Introduction

Energy in China must necessarily be viewed in a broader context shaped by a number of issues, although the most important consideration to date has clearly been economic development. As China's economy has boomed over the past 20 years, so has the need for increased energy supplies in all forms. Despite a slowdown in the economy over the past few years, China's gross domestic product is still growing and demand for electricity will still rise. Nevertheless, China's economy growth model has entered a new phase, shifting from a high growth to a medium-high growth economy. Furthermore, the government has shifted away from a policy of increasing energy supply with little regard for environmental or social impacts to one that looks to enhance environmental protection as well as to reduce greenhouse gas emissions. It is within this context that China's renewable energy program continues to garner significant attention moving forward.

In this context, in the last decade China has seen remarkable growth in the deployment of all types of energy sources in particular wind and solar power, with the government planning to add more renewable electricity capacity by 2020 and beyond. This trend has not come without problems, however. In some provinces of the country the grid infrastructure was not prepared for such an increase in electricity generation and, therefore, wind and solar photovoltaic (PV) projects cannot deliver all the electricity they produce (this problem is referred to as "curtailment"). China's economic slowdown has also led to excess electricity capacity that is too high for the country's electricity demand. Furthermore, China is also planning to expand the capacity of other power sources such as nuclear and gas by 2020 and beyond and this new capacity may only exacerbate the overcapacity problem. There are indeed several questions that have been raised about the future of China's power sector in general and its renewable energy program in particular. Despite these challenges, the government's policy is clear: move away from coal towards cleaner power sources. In order to implement this policy, the government has issued several pieces of legislation over the course of the last years, in particular starting in the 2010s, that address various aspects of the electricity sector such as power grids expansion, Feed-in Tariffs (FiT), operational hours of power plants, and power capacity targets at the national and provincial level. This legislative framework has been implemented over a number of years and is being updated from time to time to correct remaining deficiencies such as the challenge of curtailment and the expansion of the electricity grid. The latest round of policy reforms started in 2015 and the government expects these reforms to address some of the current problems in the power sector. Despite these plans, unforeseen problems could arise in the future that would further problematize China's power development.

Objectives

The goal of this work is to explain the current status of the Chinese renewable energy program (wind power and solar PV) and outline its future prospects. A related objective of this work has been to discuss China not only at the macro level (i.e. China as a single unit), but also to discuss the different financial and technical realities of the wind and solar PV sectors at the provincial level. Some aspects of this endeavor have been accomplished in this work and further research should be undertaken in order improve our understanding of renewable energy development in China and the complexity of its national and provincial system for developing wind and solar PV.

Structure Overview

In the next section (section 2), the methodological approach of this work will be presented. The third section of this study, "China's Electricity Mix", sets the stage for understanding the current status of the country's power mix. The fourth section, "China's Energy Policy", describes the government bodies that are involved in energy planning and implementation, the international policy commitments made by China to tackle climate change, and describes the government's overall plans for the power sector by 2020. Part five, "The Chinese Electricity Market", describes the main elements of the power market and the policies that make this market function. The sixth section, "Renewable Energy in China", describes the status of the wind and solar PV sector in China in terms of polices for development, location of wind and solar PV projects, operational data, and market players in both industries. Section seven, "The Economics of Renewable Energy: Wind and Solar PV" will look at the FiT system in China and at the Localized Cost of Electricity (LCOE) and it is divided in three parts: the subsection "Financial Support for Wind and Solar PV Development" describes China's FiT system for wind and solar PV projects as well as recent policy changes; the next subsection, "LCOE: Reviewing the Literature", focuses on the LCOE of solar PV and wind projects in China and will present the results of studies conducted on the issue. Other studies will also be used in order to compare the LCOE to other power sources; the final subsection "LCOE Assessment" will provide additional insights about LCOE for some provinces.

Finally, part eight will present some observations concerning the 2015 reforms of the power sector and part nine will present overall conclusions.

2. Methodological Approach

A combination of quantitative and qualitative data will be used for the analysis of the country's renewable energy program. The quantitative analysis will cover areas such as power demand/supply dynamics, including electricity capacity and production, FiT costs, and the economics of renewable energy. The data for this assessment has been gathered from government sources (e.g. the China Electricity Council, the National Energy Administration), annual reports of electric utilities companies, and other expert analyses assessing China's power sector. The qualitative analysis mainly covers the areas related to environmental and power policy, including the 2015 reforms of the power sector. Data gathered includes government documents, reports from international organizations, electric utilities reports, and expert studies.

The combination of this information will allow a number of observations to be made concerning the status and future of the country's renewable energy program, including in the context of the latest changes in policy for the renewable energy sector.

Challenges for analysis

The main challenge for this work has been the assessment of the LCOE. No studies have been found that assess the LCOE of wind and solar power in China and compare them to other sources of power using the same LCOE methodological approach. Only one study has been found addressing LCOE for wind and solar PV as well as coal using similar LCOE methodologies and this study will be used in this work in order to compare the LCOE of these projects. Moreover, other studies have been found that discuss LCOE for wind and nuclear projects separately, but the results are based on different assumptions and methodologies for calculating the LCOE. However, for the purposes of this work, the LCOE of these studies will also be used as they still allow for comparison and some useful observations.

An additional challenge is related to the impact that the last round of policy changes in the power sector will have on the electricity market and the development of renewable energy. As the changes only started in 2015 with additional legislation being issued in 2016 and 2017, there are no enough data points to identify trends concerning the future of the power sector. Nevertheless, a quantitative effort will be made to make a number of observations concerning future potential developments.

Finally, it is important to note that this analysis has not focused on issues such as, for example, the electricity grid in China, which would require a detailed analysis to assess the current status and future plans concerning grid expansion. An efficient grid helps transferring the power overcapacity from one province to those that, for example, have less power capacity and higher demand. Moreover, this analysis has not included an analysis of all power sources that could provide additional information on why there is chronic low operational hours of, for example, thermal and hydropower plants. Although these two and other issues are important and will be briefly discussed, they will remain outside the scope of this work.

3. China's Electricity Mix

According to the China Electricity Council (CEC), in 2016, China's total gross electricity capacity was 1,645 GW comprised of coal (942 GW), hydropower (332 GW), wind (148 GW), natural gas (70 GW), solar (77 GW), nuclear (33 GW), and other sources[1]. As Figure 1 below shows, coal still plays a major role in China's electricity mix, although the current level is already down from previous years, and the government plans to reduce this share even further in the coming decades. However, given its low cost and energy security implications, it is expected that coal will be still an important component in China's electricity mix.

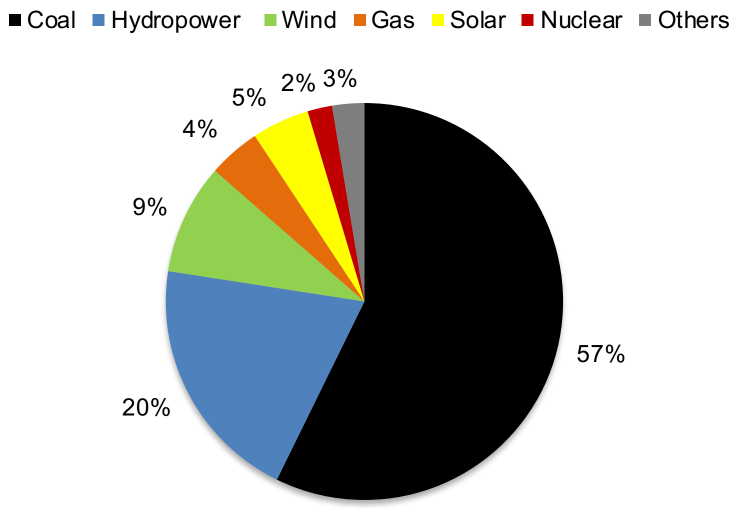
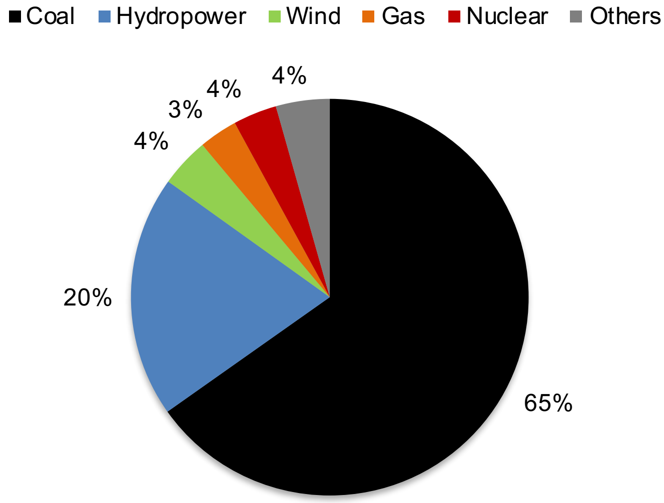


Figure 1. China's Electric Power Capacities by Source in 2016 (GW)

Total electricity generation in China in 2016 was 5,989 terawatt-hours (TWh) to cover an electricity demand of 5,919 TWh. China's mix of electricity generation in 2016 was comprised of coal (3,905 TWh), hydropower (1,180 TWh), wind (241 TWh), nuclear (213 TWh), natural gas (188 TWh), and other sources (262 TWh), including 66.2 TWh of solar PV[2].

Figure 2 shows the percentage breakdown for China's total electricity generation by power source in 2016.

[1] China Electricity Council. Statistics 2016
[2] China Electricity Council. Statistics 2016



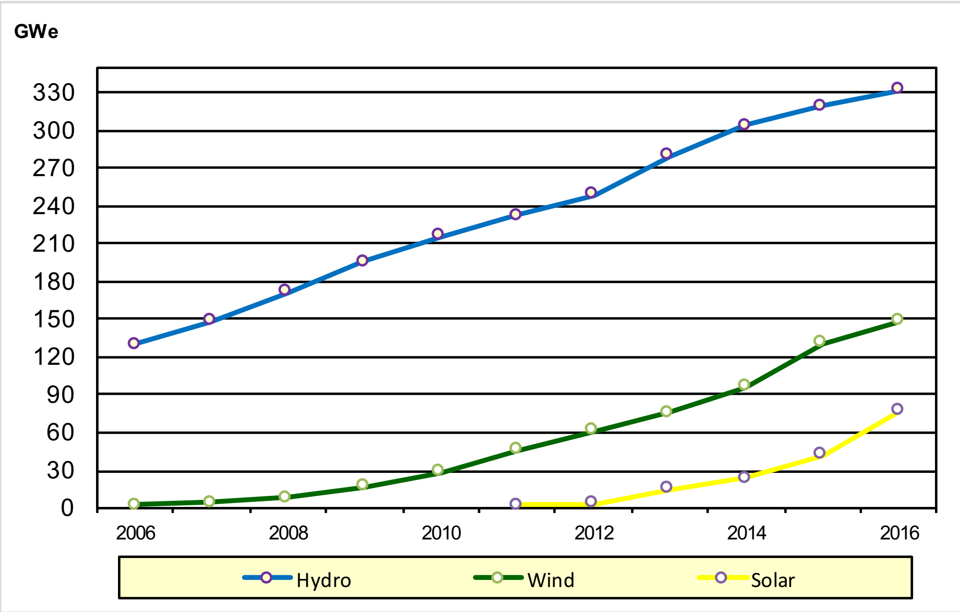
Source: China Electricity Council

Figure 2. China's Electric Power Generation by Source in 2016 (TWh)

Renewable Energy Development

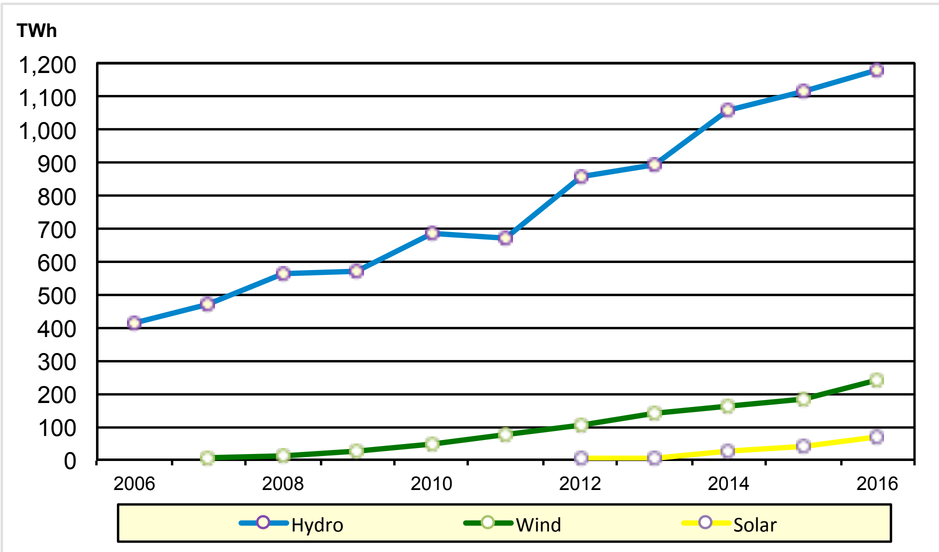
Figures 3[3] and 4[4] show the development of renewable energy (hydro, wind, and solar) in China in terms of GW and TWh for the period of 2006-2016. As the figures show, hydropower has traditionally been part of China's electricity mix and, therefore, it has had historically more capacity and generation than wind and solar power. In terms of capacity, both wind and solar power have seen a remarkable increase in the last ten years. Concerning wind power, this electricity source started with 2 GW in 2006 and reached 148 GW in 2016 (Figure 3). In terms of generation, statistics of wind power start in 2007 with 6 TWh and it reached 241 TWh in 2016 (Figure 4). Regarding solar PV, solar power started with 25 MWe in 2009 and reached 77 GW in 2016 (Figure 3). In 2012 solar power produced 3 TWh reached 66 TWh in 2016 (Figure 4).

[3] China Energy Portal. Statistics 2006-2016
[4] China Energy Portal. Statistics 2006-2016



Source: China Energy Portal

Figure 3: Renewable Energy in China – Installed Capacity (Cumulative) (2006-2016)

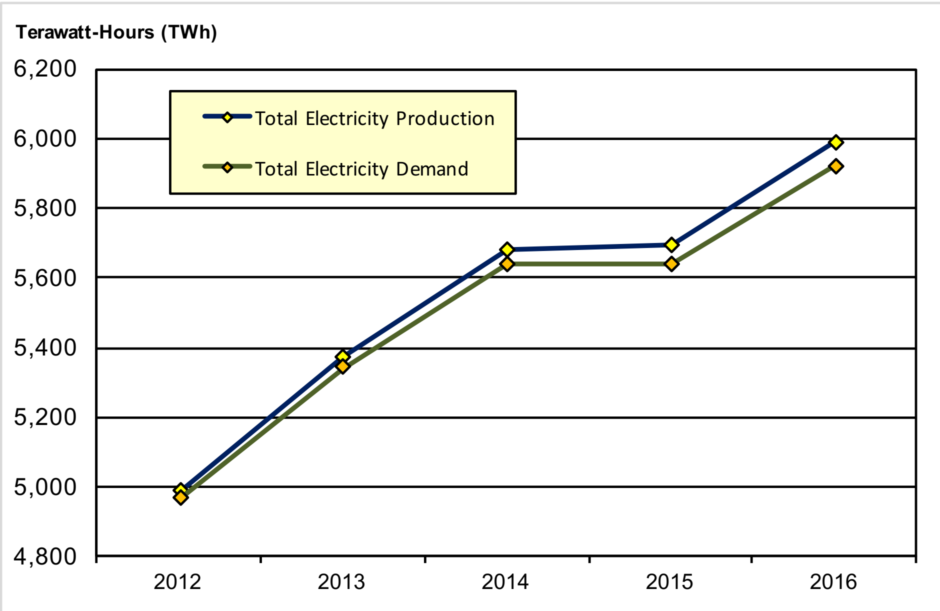


Source: China Energy Portal

Figure 4: Renewable Energy in China – Electricity Generation (2006-2016)

Electricity Supply and Demand dynamics

As mentioned before, according to CEC China's total generation in 2016 was 5,989 TWh, which represents an annual increase of 5.2% when compared to 2015. As Figure 5 shows, China's electricity demand has been increasing and generation has covered this demand with some level of excess generation. Since 2013, demand and supply have remained in the range of 5,000-6,000 TWh. During the period 2012-2014 there was a clear increase in demand, but there was a slowdown in 2014-2015. Electricity demand and generation increased again in 2015-2016.

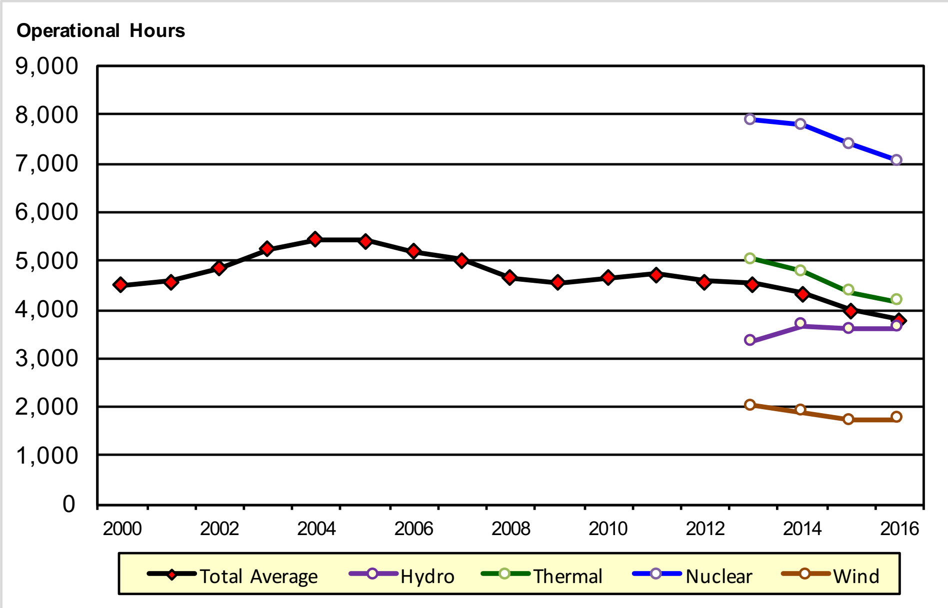


Source: China Electricity Council

Figure 5: Electricity Supply and Demand in China

However, the average operational hours of the plants that generated electricity in China, illustrated in Figure 6, demonstrate that Chinese power plants have operated at low operational hours for an extended period of time with nuclear power plants operating at higher hours when compared to the other electricity sources during the 2013-2016 period. The average operational time in 2016 was 3,785 hours, which was 203 fewer hours when compared to 2015. According to CEC, this is the lowest number of operational hours since 1964[5].

[5] China Energy Portal: 2016 Full Load Hours for Hydro, Nuclear, and Wind Power by Province



Source: China Electricity Council

Figure 6. Average Operational Hours of Power Plants in China

Summary

One of the main challenges for the Chinese electricity market is to meet demand for electricity in an efficient manner. As the Figures 5 and 6 show, although China has been able to meet electricity demand with some excess of electricity, this has been done by running, for example, thermal and hydropower[6] plants at low operational hours. Except for nuclear reactors, low operational hours have been the standard and not the exception in the Chinese electricity market. Moreover, China is expecting electricity demand to increase by 2020 and the government has outlined a plan to also increase electricity capacity. China has increased the role of wind and solar power in the last ten years and additional capacity is planned. As it is clear that China is not operating current power plants at high operational hours, more electric capacity seems not to be the best approach to meet electricity demand. There are

[6] Hydropower in China has also been suffering from curtailment and the government is taking steps to address this issue. For example, in China's "13th Five Year Development Plant for Renewable Energy" the government stated that "Sichuan and Yunnan provinces, where hydropower curtailment is severe, will have a moratorium on development of small hydropower and of medium-sized hydropower without dispatching control, over the 13th FYP period" China Energy Portal (2016): 13th FYP Development Plan for Renewable Energy; The Lantau Group. China Renewables Curtailment.

many actions that the government still needs to undertake in order to improve the electric power system in China and policy reforms are being implemented to address several issues.

4. China's Energy Policy

China's energy policy is based on the country's Five Year Plans (FYPs), which outline China's policies in all sectors. These plans are approved every five years after a drafting process that includes several government bodies and they are eventually approved by the People's Congress.

In addition to these domestic policies, international commitments could also be considered as part of the country's policies as these also codify the government's intentions concerning renewable energy and climate change. However, these commitments mostly reflect national legislation and usually do not represent any additional efforts from China.

Government bodies

As China remains a one-party state, the government is heavily involved in guiding energy and power generation policies and maintains direct ownership of key power companies. There are several key government agencies that are involved in shaping the country's energy policies.

- ***State Council***

  The State Council executes laws and supervises the entire government bureaucracy by carrying out the administrative functions of the Chinese government. The Premier heads the Council and is assisted by the Vice-Premiers, the ministers and chairmen of the commissions. The State Council ultimately assumes ownership of all policy decisions, including final decisions on the all-important FYPs[7].

- ***National Development and Reform Commission (NDRC)***

  The NDRC is a department of the State Council, which acts as the country's macro-economic planning and regulatory department and it is responsible for drafting all FYPs[8].

- ***State-owned Assets Supervision and Administration Commission (SASAC)***

  Under the State Council, SASAC supervises and manages state-owned enterprises (SOEs). SASAC also promotes the reform and restructuring of SOEs and advances the establishment of modern enterprise systems in SOEs. It is important to note that in

[7] The People's Republic of China. The State Council.
[8] National Development and Reform Commission. Main Functions of the NDRC.

the last decade China has started to liberalize some of its SOEs exposing them to market forces. While the central government still maintains full ownership of the main electricity suppliers, many subsidiaries of these SOEs have launched Initial Public Offerings and are now traded in a number of stock markets and have shareholders[9].

- ***National Energy Commission (NEC)***

  The NEC is responsible for drafting energy development strategies, evaluating energy security, and coordinating international cooperation on climate change, carbon reduction, and energy efficiency. The members of the NEC include the Premier, Vice-Premier and other high level officials from various departments[10].

- ***National Energy Administration (NEA)***

  Within the NDRC, the NEA is an agency responsible for:

  - Formulating and implementing energy development plans and industrial policies
  - Promoting institutional reforms in the energy sector
  - Administering the energy sectors including coal, oil, natural gas, nuclear power, and renewable energy
  - Approving, reviewing, and examining fixed asset investment projects of the energy sector within national plans and the scale of annual plans in accordance with the authority stipulated by the State Council
  - Undertaking the daily work of the National Energy Commission[11]

- ***State Electricity Regulatory Commission (SERC)***

  SERC is the regulator of the electricity market in China and has several functions, including, among others:

  - Establishing national power regulations and a unified power regulatory system
  - Assessing the formulation or modification of laws and regulations on electric power regulation

[9] State-Owned Assets Supervision and Administration Commission of the State Council.
[10] The State Council (2016)
[11] National Development and Reform Commission. National Energy Administration

- Participating in the formulation of national power development plans
- Setting up regional electricity markets
- Verifying the operation of the electricity market and the establishment of electric power dispatching and trading institutions
- Supervising the operation of the electricity market[12]

International Commitments[13]

China's government has dramatically increased its focus on climate change policies over the past few years. In June 2015, China submitted its "Intended Nationally Determined Contributions" (INDC) report to the Secretariat of the United Nations Framework Convention on Climate Change in which the government reported that it had started and implemented several climate change policies. In the INDC report, China also announced that based on its national circumstances, level of development, sustainable development strategy and international commitments, China has nationally determined actions by 2030 that include, among others, carbon dioxide emissions reductions and limits and further development of non-fossil fuels.

China's Five Years Plans

The central government's FYPs outline China's overall energy policy. The National People's Congress approved the 11th FYP for 2006-2010 in 2006 and the 12th FYP for 2011-2015 was approved in March 2011. The 13th FYP for 2016-2020 was approved in March 2016.

China's 13th FYP is considered the "greenest" plan to date and sets caps for energy use and levies emissions targets for city air quality, carbon dioxide intensity, and reduction in soil and water contamination[14]. Moreover, climate change mitigation and adaptation continue to be top priorities in the 13th FYP since their adoption in the 12th FYP.

13th FYP for Power Development[15]

Based on the March 2016 FYP, in January 2017 the NDRC issued the official 13th FYP for Power Development, which contains electricity targets for different generating sources. China aims to have 2,000 GW of generating capacity by 2020, of which at least 320 GW

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[12] The Central People's Government of the Republic of China: Introduction to the SERC
[13] This section is mainly based on: Department of Climate Change, National Development and Reform Commission of China (2015)

[14] United States-China Economic and Security Review Commission 2016: 3
[15] National Development and Reform Commission 2017

would come from renewable energy (wind: 210 GW and solar: 110 GW). Natural gas capacity is planned to reach 110 GW, and conventional hydropower capacity should reach 340 GW by 2020. Coal-fired plant capacity will increase, but it is planned to remain below 1,100 GW. Finally, this plan foresees roughly 58 GW of nuclear capacity by 2020. The details of the 13th FYP targets for the power industry are shown in Table 1.

Table 1. China's Power Development Targets under the 13th FYP

	2015	2020	Average Annual Increase
Total Generation Capacity (GW)	1,530	2,000	5.5%
Total Electricity Demand (TWh)	5,690	6,800-7,200	3.6-4.8%
Generation Capacity by Source (GW)			
Conventional hydro power	297	340	2.8%
Pumped-storage hydro	23	40	11.7%
Nuclear power	27	58	16.5%
Wind power	131	210	9.9%
Solar power	42	110	21.2%
Coal	900	< 1,100	4.1%
Gas	66	110	10.8%

Source: China's 13th FYP for Power Development

Focusing now on the FYPs for solar PV and wind power, Table 2[16] shows that the planned capacities in the 11th, 12th, and 13th FYPs have seen a major increase over time and that planned targets have been surpassed at least in the case of the 2010 targets (for wind) and 2015 targets (for wind and solar). As for the 2020 targets, these will most likely be met or even surpassed based on the level of deployment as of the first half of 2017 (wind: 153 GW compared to the 210 GW target for 2020; solar: 101 GW compared to the 110 GW target for 2020). It is important to note that in some cases, the initial FYP targets have been refined based on changes in deploying these energy sources. For example, in the case of the 11th FYP it was considered that the targets for wind established in 2007 were too low and they were adjusted in 2008 from 5 GW to 10 GW[17].

[16] Dewey and LeBoeuf LLP 2010: 33; Zeng Ming, Lü Chunquan, Ma Mingjuan 2012; Platts 2012; China Energy Portal 2017: Q1&2 PV installations utility and distributed by province; China Energy Portal 2017: Q1&2 wind power installations and production by province

[17] Dewey and LeBoeuf LLP 2010: 33

Table 2: FYPs Targets for Wind and Solar PV (2010-2020)

	11th FYP (2010)	Achieved	12th FYP (2015)	Achieved	13th FYP (2020)	Achieved (Q1&Q2 2017)
Wind Power (GW)	10	29	100	185	210	153
Solar PV (GW)	0.3	0,2	21	38.5	110	101

Summary

Renewable energy development in China should be analyzed in the context of China's energy strategy and policies to combat climate change. China has recognized the importance of reducing CO2 emissions and of moving away from fossil fuels. Although the process of reducing the role of coal in China's energy supply will still take many decades, the political decision has been already made and policies are currently being implemented to achieve this goal. Furthermore, the main driving force behind these changes is the central government as it is the owner of key SOEs in the power sector. The central government uses a large bureaucracy to implement the FYPs and this is not likely to change in the foreseeable future. Nevertheless, the government is trying to bring the electricity sector closer to market forces where supply and demand will determine the future dynamics of the electricity sector. This is best exemplified, for example, by the fact that some subsidiaries of SOEs now have private shareholders who are more interested in rates of return and less in energy planning. Therefore, the power sector in China is undergoing a transition in which market forces are starting to play a more important role in investment decisions.

5. The Chinese electricity market

Before explaining the situation of renewable energy in China, this chapter will offer a brief overview of the electricity market in China and the reforms that have been undertaken in recent years. The goal of this section is not a detailed analysis of these issues, but an overview that will set the stage to explain the role of renewable energy in China.

Market Reforms: Historical Background

The Chinese electricity market has seen a gradual development in the last years moving away from a fully centralized market to a market where there is more competition and more players[18]. Although not perfect, the market has developed similarly to other countries as, for example, grid management and electricity generation have been separated. According to the International Energy Agency (IEA), as of 2006, there were three main phases in the reform of the Chinese electricity sector[19]:

- In the mid-1980s the generation sector was opened to new entities outside the central government. Many of these new players were still affiliated with the government (e.g. SOEs), although it represented an opportunity for these players to become more independent.
- In 1997, the Ministry of Power Industry was broken down with its generation and grid assets being transferred to a new entity named the State Power Corporation (SPC). According to the IEA, this was the first step towards separating grid operations and generation.
- In 2002, an important policy document was issued with the consequence that the SPC was broken down and its assets were distributed among new SOEs. Five electric companies emerged from this process and they still exist today: the State Power Investment Corporation (formerly the China Power Investment Corporation), the China Huadian Corporation, the China Huaneng Group, the China Datang Corporation, and the China Guodian Corporation. Also, two grid operators were

[18] IEA 2006; Shaofeng Xu, Wenying Chen 2006
[19] IEA 2006: 33; Mun S. Ho, Zhongmin Wang, and Zichao Yu 2017: 13

established: the State Power Grid and the China South Power Grid. Table 3 summarizes these three stages[20]:

Table 3: Reform Timeline for the Electricity Sector in China

	1980-1984	1985-2001	2002-Present
Industrial Structure	Vertical Integration	Vertical Integration	Unbundled generation and transmission & distribution (2002)
Ownership	Predominantly central government owned	Central and provincial government ownership. Increasing private investment in generation	Central and provincial government ownership, declining share of private investment
Dispatch	Economic dispatch based on total embedded cost	Equal shares dispatch	Equal shares dispatch; pilot projects for energy efficient dispatch (2007)
Wholesale generation pricing	Internal transfer prices	Investment recovery based on financial lifetime (1985) Investment recovery based on operational lifetime (2001)	Benchmark price (2004) Fuel price-wholesale price co-movement (2004)

Source: University of Cambridge. Energy Research Group (2017)

The Market[21]

The reforms mentioned above and many other changes have led the Chinese electricity market to have some particular characteristics, including, among others:

- ***Renewable Energy Law***

  According to the IEA, the basis for renewable energy development in China is the Renewable Energy Law (REL)[22]. The REL mandates grid companies to purchase renewable energy generation, except when the "grid safety" is compromised. The REL also introduces a FiT scheme and province-specific targets, which have a capacity and energy component and are incorporated in the FYP for each province. The grid companies act as single buyers for all power generation built under this law.

[20] Michael G. Pollitt, Chung-Han Yang, Hao Chen 2017: 4
[21] This section is mainly based on Huaneng Power International 2017: 3, 4, 14, and 17.
[22] IEA 2016: 87.

- ***Approval Process***[23]

  Before July 2004, any project proposal for new power plants had to be submitted first to the NDRC for approval and then be submitted to the State Council. In July 2004, the State Council reformed the approval process and now new projects that do not use government funds are no longer subject to this approval procedure. Instead, they are subject to a confirmation and registration process. In the case of renewable energy, wind power projects with installed capacity of 50 MWe or above are subject to confirmation and registration with the central government, while wind power projects with installed capacity lower than 50 MWe are subject to confirmation and registration with provincial departments. Wind power projects confirmed by local government departments at provincial level still need to be registered with the NDRC and the China National Energy Administration. Moreover, at the provincial level solar PV projects are regulated in accordance with the guidelines of the State Council.

- ***On-Grid Tariffs/Feed-in Tariffs***[24]

  "Feed-in Tariff" refers to the guaranteed fixed tariff that producers receive for the electricity generated (expressed usually in RMB/kWh or RMB/MWh). These tariffs are defined as:

  > *"The price of electricity per kWh for which a power project could sell the electricity it generated to the power grid companies. On-grid tariff includes (1) benchmark or approved on-grid tariff; (2) tariff premiums for wind power companies to compensate the costs of transmission lines that wind power companies constructed and owned (if applicable); and/or (3) discretionary tariff subsidies granted by the local government (if applicable)"*[25]

  Therefore, while the first component of the tariff always applies, the other two components could be part of the FiT or not. Moreover, according to the IEA:

[23] Huaneng Power International 2017: 14
[24] Huaneng Power International 2017: 3. Reports of electric utilities in China refer to FiT as "On-Grid Tariffs". Other sources use only the term "Feed-in Tariff". Both terms have the same meaning. In this work, the term FiT will be used unless when quoting directly from other sources.
[25] China Datang Corporation Renewable Power Co, Limited 2016: 255.

"The payment comprises two elements. The first element is paid by the grid companies and payment equals the local on-grid tariff for coal-fired power plants." [26]

The second element of the FiT is paid by the government:

"the difference between the local on-grid coal tariff and the applicable FIT is paid from the National Renewable Deployment Fund (NRDF). The component covered by the NRDF is larger than that paid by grid companies."[27]

According to the IEA, the NRDF is financed by a general levy on electricity bills and since 2013 rapid renewable energy deployment has driven up the costs of the FiT system and put pressure on NRDF financing. As such, there is pressure on the government to find alternative revenue sources to finance the targeted development based on the 13th FYP[28].

Finally, FiTs vary from province to province and there are also differences within provinces as the FiT depends on the availability of local resources that rely on weather conditions for wind or solar power.

- ***Power Sales***[29]

Power plants sign agreements with local grid companies for the sales of its planned power output. The agreement usually has a fixed term of one year and outlines that the annual utilization hours of the power plant will be determined with reference to the average annual utilization hours of similar generating units connected to the same grid. In 2003, the government released a "Model Contract Form" to be used by grid and generation companies in connection with their electricity transactions. The Model Contract Form contains provisions on the parties' rights and obligations, amount of electricity subject to purchase, payment method and liabilities for breach of contract, and other issues. It is considered that this form has facilitated the negotiation and execution of electricity purchase contracts between power grid companies and power generation companies in a fair, transparent and efficient manner. Many agreements

[26] IEA 2016: 90.
[27] IEA 2016: 90.
[28] IEA 2016: 90.
[29] Huaneng Power International 2017: 21

between power plants and local grid companies are based on the Model Contract Form.

- ***Power Sales through Competitive Bidding***[30]

  In 1999, the government started a program for power sales using competitive bidding. The FiT for power sold through competitive bidding is generally lower than the pre-approved FiT tariffs for planned output. The central government is seeking to expand the program, but the negative aspect is that any increased power sales through competitive bidding may reduce companies' FiT and may adversely affect their revenue and profits.

- ***Direct Power Purchase by Large Power Users***[31]

  In 2009, the central government started promoting the practice of direct power purchase by large power users. According to existing regulations, the direct transaction price is determined through negotiation between the generator and the consumer. Moreover, the price should take into consideration issues such as the supply and demand in the power market and the structure and level of development of local economy. In 2013, the government officially launched the direct power purchase program in seven provinces that has since been extended to other provinces. The national volume of electricity sold in 2016 via the direct purchase programs was approximately 800 billion kWh, which was higher than the 430 billion kWh sold in 2015. Most of the transactions were negotiated between power producers and large end users, with a small amount completed through the competitive bidding process.

- ***Dispatch***[32]

  Power plants deliver electricity to meet planned generation. Planned generation is subject to local demand and dispatching to the electric grid by the dispatch centers of grid companies at the local level. The dispatch of electric power generated is controlled by the dispatch center of the applicable grid company pursuant to a dispatch agreement with the generator and to governmental dispatch regulations. In each market, companies compete against other's power plants for power sales. There are no assurances that the full amount of the planned generation will be dispatched by

[30] Huaneng Power International 2017: 3
[31] Huaneng Power International 2017: 3 and 21
[32] Huaneng Power International 2017: 4

the dispatch centers. For utilities, a reduction in electricity delivered by the dispatch center could have a negative effect on profitability.

- ***Grid interconnections***

  As noted above, in 2002 the SPC was broken down and its assets were distributed among new SOEs. As a result of this process, two grid operators were established: State Grid Corporation of China and China South Power Grid.

  State Grid Corporation of China (SGCC)[33]

  SGCC is a SOE that provides power to over 1.1 billion people in several provinces, autonomous regions and municipalities, and is the largest grid operator in China covering 88% of the Chinese territory.

  China South Power Grid (CSG)[34]

  China Southern Power Grid Company is also a SOE that constructs and operates the power grids in Guangdong, Guangxi, Yunnan, Guizhou, and Hainan provinces.

  As Figure 7[35] shows, for grid purposes, China is divided in six areas and SGCC and CSG have a monopoly over the country with SGCC being the largest grid operator. SGCC operates the northern grids, where most of the potential wind power is located.

[33] State Grid Corporation of China
[34] China South Power Grid
[35] National Energy Administration 2016: 8

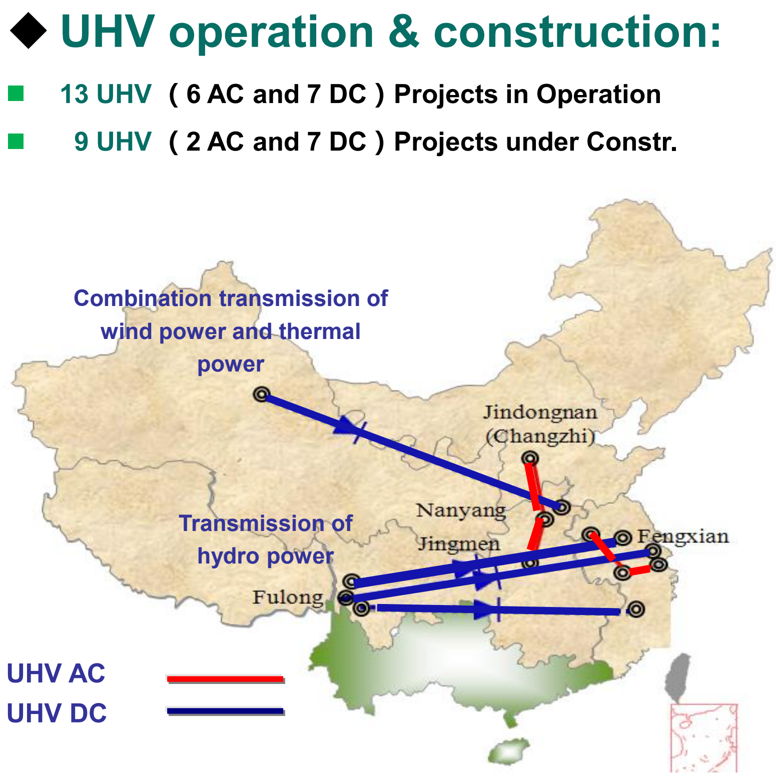
Figure 7: Grid Companies and the Areas Where They Operate

Source: China National Energy Administration (2016)

Furthermore, there are several Ultra-High-Voltage lines that are in operation or under construction in China. Figure 8[36] shows, for example, the lines that SGCC is operating and expanding.

[36] State Grid Corporation of China 2017: 9

Figure 8: Ultra High Voltage Projects in Operation and Under Construction



Source: SGCC (2017)

2015 Reforms

The latest effort to reform the Chinese electricity sector took place in March 2015 as the Central Committee of the Chinese Communist Party and the State Council published several documents on the power system reform in which the government outlined some basic principles and objectives: energy conservation, emission reduction, and promotion of energy infrastructure optimization to increase the proportion of renewable energy in power generation. In March 2015, the State Council issued the document "Deepening Reform of the Power Sector" (known as "Document Number 9"), which provides five basic principles[37]:

- The need for reliability in the electricity system
- Bringing the electricity market closer to market dynamics (e.g. electricity trading, market price mechanisms)
- Protection of consumers (e.g. affordability in terms of costs)
- Energy savings, emissions reductions, and development of renewable energy
- Better governance and regulation

[37] CPC Central Committee and the State Council 2015; Max Dupuy, Frederick Weston, Anders Hove 2015: 6

Document Number 9 also contains specific tasks to reform the Chinese power sector such as, among others, tariff reforms, promoting electricity trading, and establishing independent power trading organizations. The document is essentially a broad roadmap for reforming the power sector and since the document was released, several other supporting regulations have been issued. Table 4[38] provides a summary of recent electric power market reform policies announced by the Chinese government.

[38] Michael G. Pollitt, Chung-Han Yang, Hao Chen 2017: 7

Table 4: Document Number 9 and Reform Process

<table>
<tr><th>Policy Goals</th><th>Supporting Documents</th><th>Reform Process</th></tr>
<tr><td>Promoting electricity power pricing mechanisms</td><td>Implementing Opinions on Document No. 9

Implementation Opinions on Promoting Transmission-Distribution Price Reform</td><td rowspan="7">The Chinese State Council and CPC Central Committee issued the 'Opinions on Further Deepening Power Sector Reform' (Document No. 9) in March 2015. There are two main stages for this round of electricity reform in China. In the first stage (from March to June 2015), NDRC and other related governmental agencies announced five supporting documents. In the second stage (November 2015), NDRC and NEA issued another six supporting documents. These supporting documents provide the practical guidance for implementing the seven main policy goals set in the Document No.9, which cover the issues of electricity price, power trading system, wholesale side design, power grid and governmental supervision.

Electricity ancillary services in China have long been provided by grid-connected power plants. Document No.9 changes this situation by establishing a new "shared responsibility" mechanism. This "shared responsibility, shared gains" mechanism improves the original compensation mechanism, and welcomes user participation in ancillary services by contracting with either generator companies or the grid. In March 2015, the supplement policy document - Guiding Opinions on Improving Electric Operation and Regulation to Promote Greater and Fuller Use of Clean Energy – was published, which aims to advance the ancillary services and promote renewable energy consumption at the same time.</td></tr>
<tr><td>Reforming power trading systems and refining market-oriented trading systems</td><td>Notification of Perfecting Formation Mechanism of Trans-Provincial and Trans-Regional Power Trading Prices

Implementation Opinions on Promoting Power Market Construction</td></tr>
<tr><td>Reforming power generation, power utilization and the current market mechanisms</td><td>Notification of Perfecting Power Emergency Response Mechanism and Comprehensive City Pilots of Managing Power-Demand Side

Implementation Opinions on Orderly Releasing Plans for Power Generation and Power Utilization</td></tr>
<tr><td>Establishing independent electricity trading institutions and a fair and regulated trading platform</td><td>Implementation Opinions on Establishing Power Trading Institutions and Their Normative Operation</td></tr>
<tr><td>Steadily reforming power sales side and distribution</td><td>Implementation Opinions on Promoting Power Sales Side Reform</td></tr>
<tr><td>Enhancing fair access to power grid and power transmission</td><td>Guidance Opinions on Improving Power Operation Adjustment to Facilitate Multiple and Full Development of Clean Energy

Guidance Opinions on Reinforcing and Regulating Supervision and Management of Coal-Fired Self Generation Power Plants</td></tr>
<tr><td>Reinforcing electricity safety, scientific supervision and an integrated power planning system</td><td>Supervision and Examination Procedures for Pricing Costs of Power Transmission and Distribution (Trial)</td></tr>
</table>

Source: University of Cambridge. Energy Research Group (2017)

Summary

As described in this section, the Chinese power market is undergoing a long process of reform, with the latest round in 2015. One trend is towards bringing more market forces to improve the efficiency of power sector. This was illustrated, for example, when the government allowed stakeholders to enter into contracts independently. Nevertheless, the government still maintains oversight of demand and supply dynamics as well as the activities of stakeholders (e.g. the number of hours a power plant can operate or the regional capacity to be deployed). The existing system has led to a situation in which there is overcapacity in the power sector and this has also affected renewable electricity generation as, for example, the lack of electricity grids in certain provinces made it difficult to transport the electricity produced and has led to low operational hours.

6. Renewable Energy in China

This part will explain the status of wind and solar PV projects in China and will also provide the necessary data to better understand the economics of wind and solar PV discussed in section 6. First, this part identifies the wind and solar PV projects that are located all over China and provide, if available, operational data about them. Next, it discusses China's renewable energy polices in particular the FYP for 2020 and its targets for wind power and solar PV. Finally, it explains China's renewable generation industry focusing on a number of large enterprises that operate wind and solar PV projects. Figure 9 helps visualize the location of these projects in several Chinese provinces.

Figure 9: Map of China

As mentioned before, according to the CEC, in 2016, China's total gross electricity capacity was 1,645 GW, which included 148 GW of wind (9%) and 77 GW of solar (5%) capacity. Total electricity generation in China in 2016 was 5,989 terawatt-hours (TWh) that included 241 TWh of wind (4%) and 66 TWh of solar PV. Wind and solar generation capacity is distributed all over the country, although there is a regional variation in terms of scale.

Wind Power and Solar PV potential

Before discussing in detail the status of wind power and solar PV in China, it is worth explaining some of the existing forecasts about potential wind and solar power capacity development in China. Also, an overview about the potential deployment, from the technical point of view, of these two sources will be provided.

- ***IRENA***

  In 2014, the International Renewable Energy Agency (IRENA) released its Renewable Energy Roadmap (REmap) report "Renewable Energy Prospects: China"[39]. In the REmap reports, IRENA assesses how countries can work together to double the share of renewable energy in the global energy mix by 2030[40].

  In this special report about China, IRENA discussed, among others, the current status of renewable energy in China, policies for implementation, scenarios for future development, as well as the potential of renewable energy in the future. IRENA calculates that the share of renewables in China's energy mix (excluding biomass) will increase to 16% by 2030 (from 7% in 2010) under the reference case in this report (business as usual scenario)[41]. The specific potential targets for wind and solar PV in the reference case scenario include:

  - Wind: 500 GW by 2030 (first half of 2017: cumulative installed capacity amounts to 153 GW)
  - Solar PV: 308 GW by 2030 (101 GW deployed in the first half of 2017)

  As the these estimations show, in the case of wind and solar PV, China is still a long way from meeting the targets outlined by IRENA. The 13th FYP envisions 210 GW of wind power and 110 GW of solar PV by 2020. Therefore, the IRENA targets by 2030 foresee more than 100% increase in 10 years when compared to the 2020 FYP targets for wind and solar PV development.

- ***China National Renewable Energy Centre (CNREC)***

  In 2014, CNREC issued a report entitled "China Wind, Solar and Bioenergy Roadmap 2050 Short Version" in which it, together with other organizations, carried out research on medium and long-term wind, solar and bioenergy roadmaps.[42] This

[39] IRENA 2014
[40] IRENA 2014: Foreword
[41] IRENA 2014: 2
[42] CNREC 2014: Foreword

report has also developed a base case scenario for wind and solar power with the results shown in Table 5[43]:

Table 5: CNREC Wind and Solar PV Scenarios (Base case)

	2020	2030	2050
Wind Power (GW)	200	400	1000
Solar PV (GW)	105	430	1180

As Table 5 shows, looking at the 2030 scenarios, CNREC is less optimistic about the development of wind power by 2030 (400 GW Vs. 500 GW in IRENA's report), but it is more optimistic about solar PV in 2030 (430 GW Vs. 308 GW in IRENA's report). Concerning deployment by 2020, CNREC's targets are very close to the level of development by 2017, in particular when it comes to solar PV.

- ***Technical Resource Potential***

Table 6[44] shows what is the potential of solar PV and wind power in China from the technical perspective. As the data shows, even if China were to deploy a lot of capacity by 2050, as outlined by CNREC, this technical potential would not be achieved.

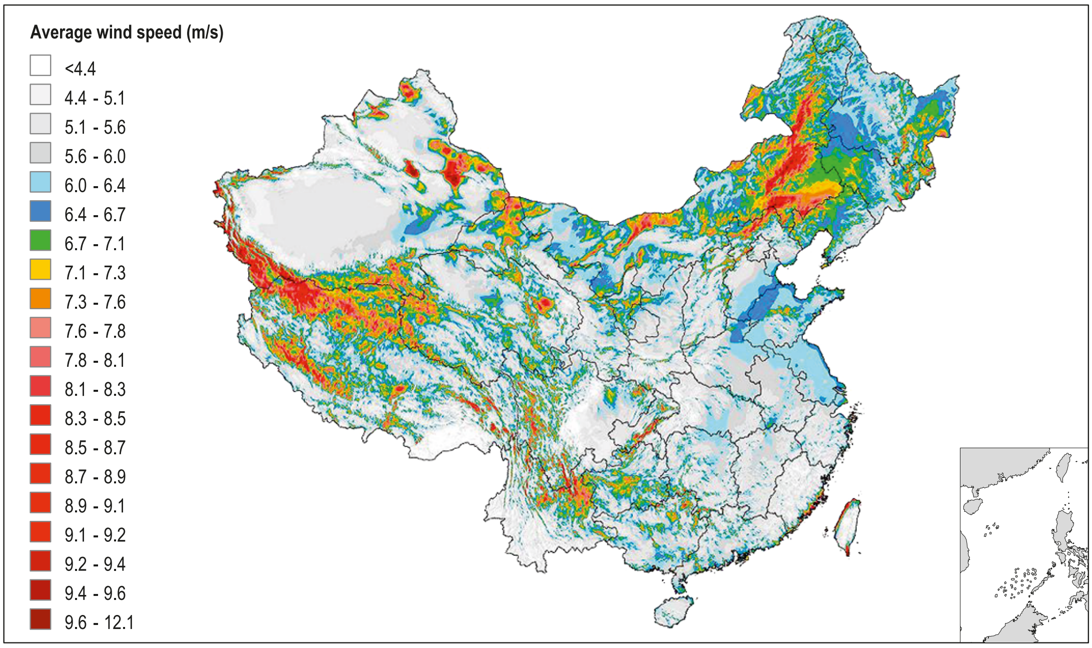
Table 6: Wind Power and Solar PV (Technical Potential)

Source	GW
Onshore Wind (>50m)	1300-2600
Offshore Wind (depth 5-25 m)	200
Solar PV (utility)	2200
Solar PV (rooftop)	500

Provincial distribution of wind projects

Figure 10[45] shows the areas that are, from the technical point of view, best suited for wind power and these areas located in Inner Mongolia, Jilin, Tibet, and also parts of Xinjiang. On the other hand, the South west of China is not ideal for wind projects.

[43] CNREC 2014: 3 and 12.
[44] IRENA 2014: 47
[45] IEA 2016: 80



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Source: International Energy Agency (2016)

Figure 10: Average Wind Speed in China

Figure 11 shows (data contained in Table 21[46] in the Appendix) that wind projects are located all over the country, but most of the capacity is concentrated in few provinces. In 2016, Inner Mongolia was the province where most of the wind capacity was located (25.5 GW) followed by Xinjiang (17 GW) and Gansu (12.7 GW).

[46] China Energy Portal: 2016 Wind Power Installations and Production by Province

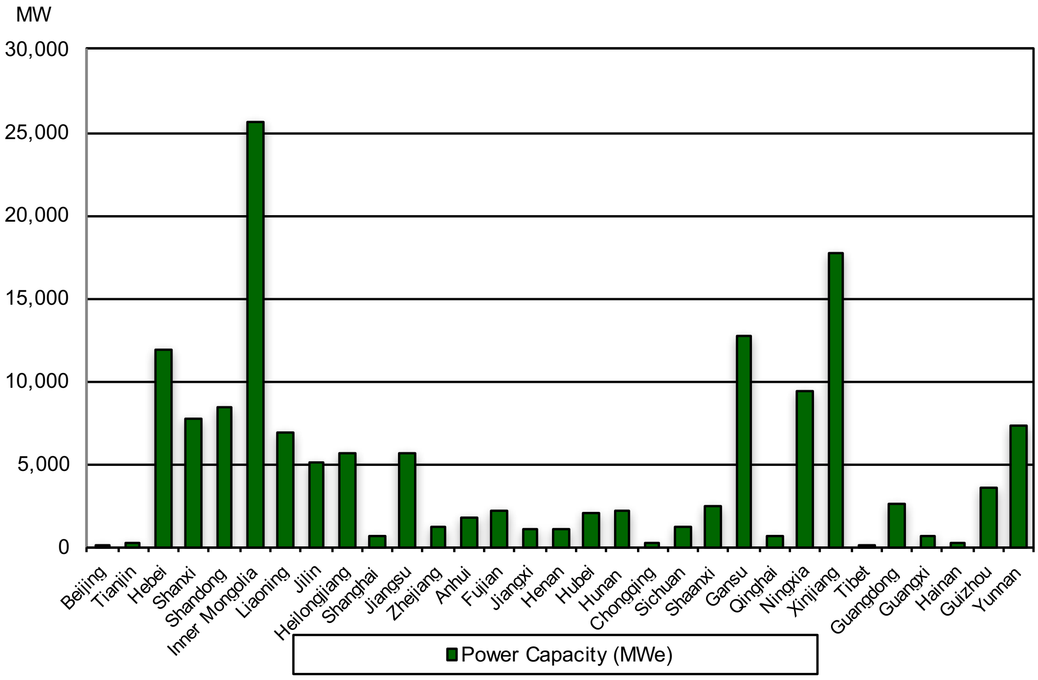


Figure 11: Wind Power Capacity by Province in 2016 (MWe)

Moreover, Figure 12[47] shows that the province that produced most of the wind electricity in 2016 was Inner Mongolia (46,400 GWh) followed by Hebei (21,900 GWh) and Xinjiang (22,000 GWh). Note that although Gansu had slightly more wind capacity than Hebei in 2016, Hebei managed to produce more electricity than Gansu, namely 21,900 GWh compared to 13,000 GWh respectively. This was the result of almost 10,400 GWh of wind power curtailment in Gansu in 2016.

[47] Data in Table 21 in the Appendix

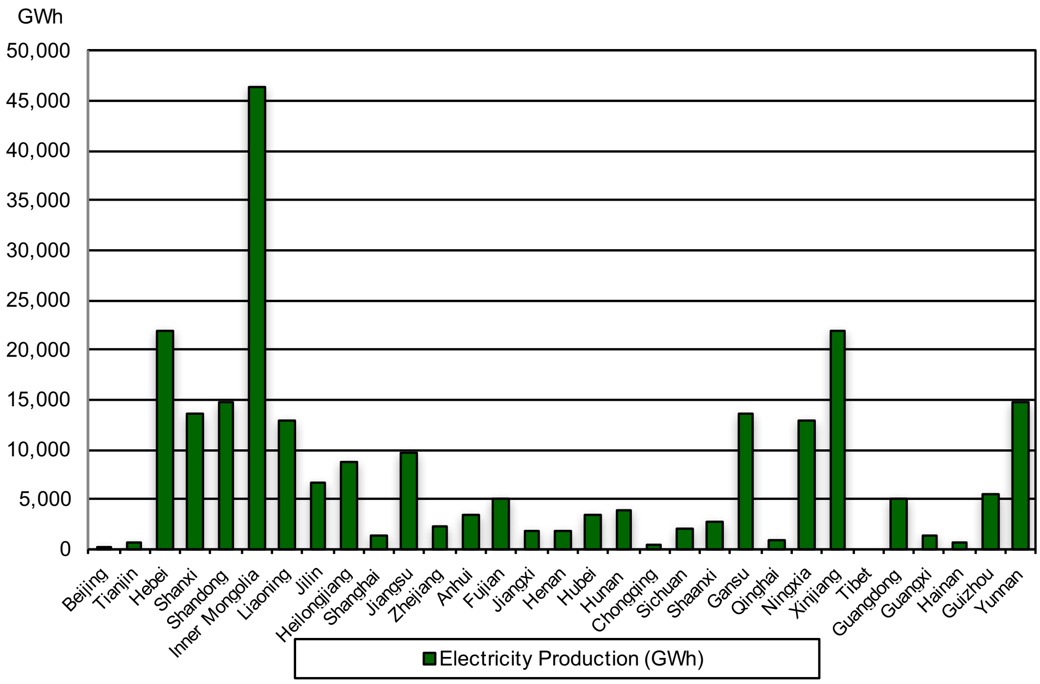


Figure 12: Wind Power Production by Province in 2016 (GWh)

Figure 13[48] shows the 2016 FLH (Full Load Hours) of wind power in China. The provinces with the highest utilization hours include Fujian (2,500 hours), Guangxi (2,365 hours), Sichuan (2,247 hours), and Yunnan (2,223). The provinces with the lowest FLH in 2016 were Gansu and Xinjiang. Note that although Inner Mongolia hosts most of the wind capacity and generation in China, in 2016 the province had fewer FLH than the mentioned provinces. The wind power curtailment in Inner Mongolia in 2016 was 12,400 GWh. This shows that even under negative circumstances (low FLH and high curtailment), Inner Mongolia is an excellent wind power producer.

[48] Data in Table 21 in the Appendix

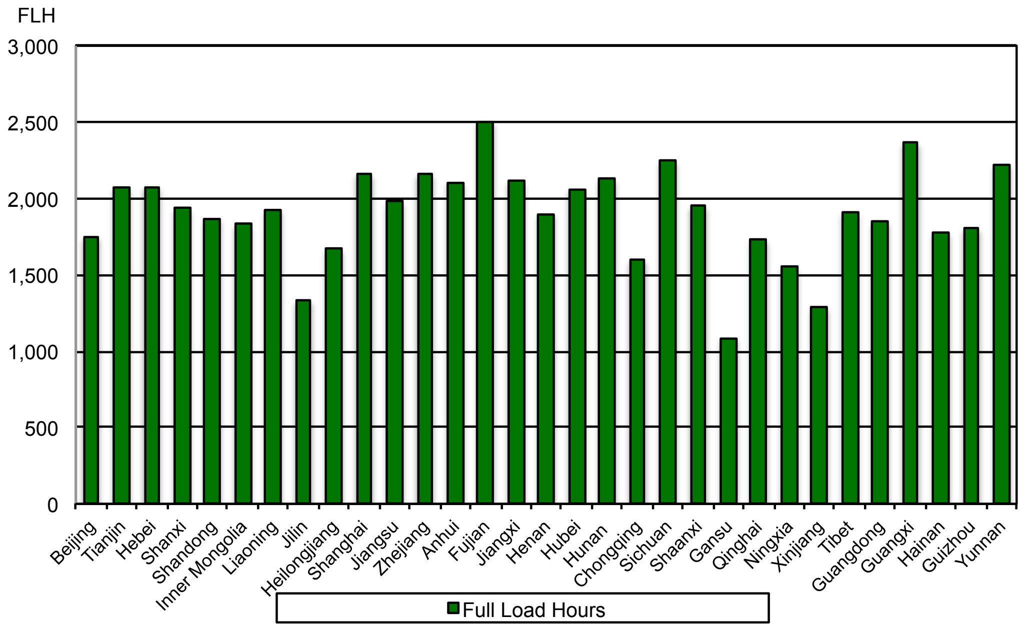


Figure 13: Wind Power Full Load Hours by Province (2016)

Figure 14[49] shows that three provinces faced dramatic levels of wind power curtailment in China in 2016: Inner Mongolia (12,400 GWh), Gansu (10,400 GWh), and Xinjiang (13,700 GWh). The total GWh curtailment reached 49,600 GWh in 2016, which was roughly 20% of total wind generation.

[49] Data in Table 21 in the Appendix

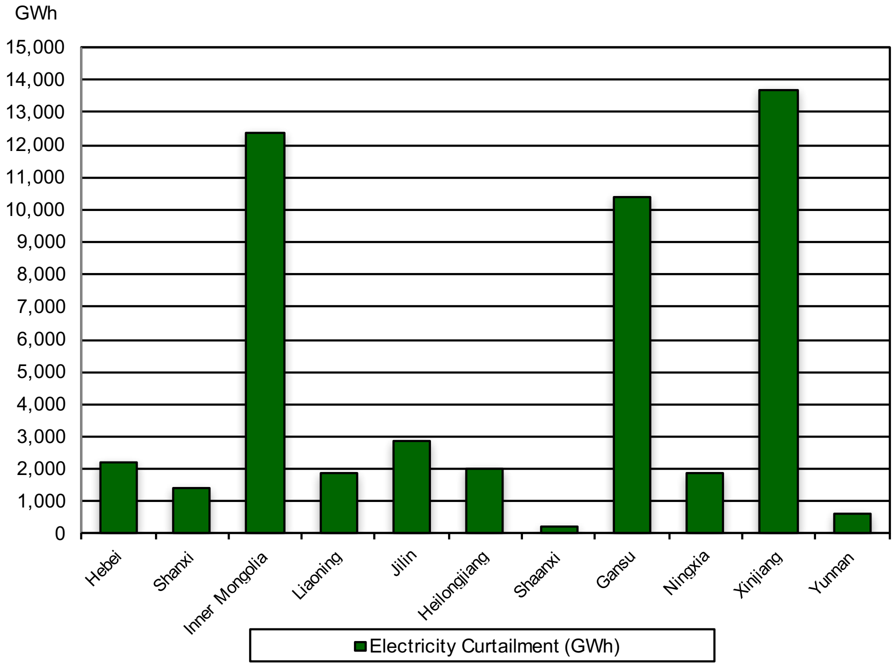
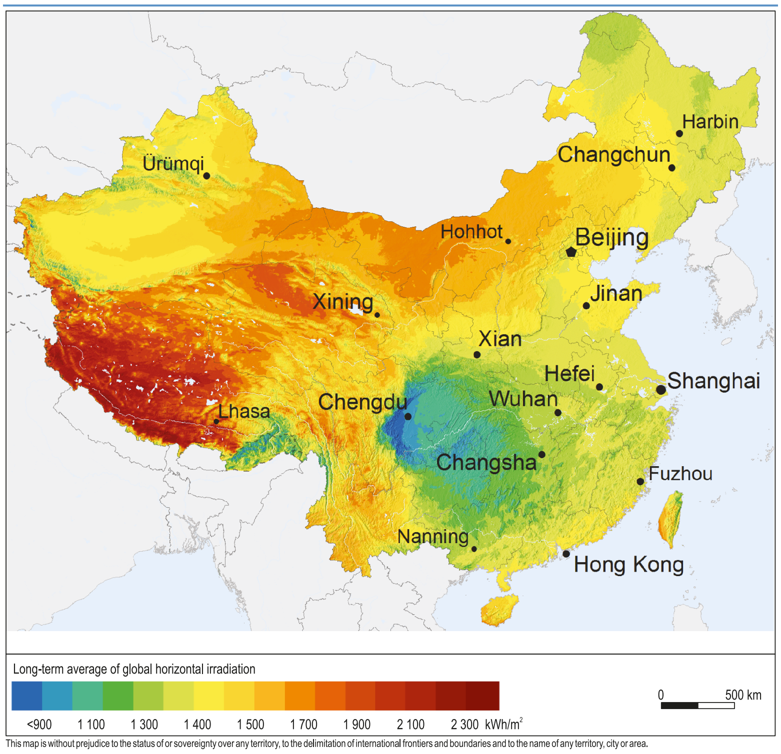


Figure 14: Wind Curtailment in 2016 (GWh)

Provincial distribution of solar PV projects

From a technical perspective, as Figure 15[50] shows, most of the solar radiation in China is concentrated in the western part of the country, in particular in Tibet. Moreover, Table 7[51] shows the IEA's assessment of the irradiation levels and EUH (Equivalent Utilization Hours) in the existing three resource zones for solar PV projects (more information about these three zones is contained in Table 13). Note that the zones offer different levels of radiation and operational hours and these two factors are important when determining FiT for solar projects.

[50] IEA 2016: 79
[51] IEA 2015: 34



Source: International Energy Agency (2016)

Figure 15: Average Annual Global Horizontal Irradiation in China

Table 7: Irradiation and Annual EUH in China's Three Resource Zones

Resource Zone	Annual Ground-Surface Global Irradiation (kWh/m^2)	Irradiation on Inclined PV Surfaces (kWh/m^2)	Annual EUH
I	1,500-2,000	1,725-2,300	1,380-1,840
II	1,240-1,500	1,389-1,680	1,100-1,345
III	<1,240	1,320	1,056

It is important to note that there are two types of solar systems in China, namely Centralized PV Systems and Distributed Systems[52]. The centralized systems refer to utility-scale farms that can produce large amounts of electricity. The PV distributed generation systems are smaller and its capacity can range from kilowatts to several megawatts. In 2016, China's PV capacity was roughly 77 GW of which roughly 67 GW was based on centralized systems. This difference is important as it helps explain some statistical differences when reporting

[52] DBS Asian Insights 2016: 22

China's total solar PV capacity. Figure 16 shows (this figure is based on Table 22[53] in the Appendix), that these two systems are distributed all over the country. The provinces with the highest total solar capacity include Xinjiang (8,620 MW), Gansu (6,860 MW), Quinghai (6,820 MW), and Inner Mongolia (6,370 MW).

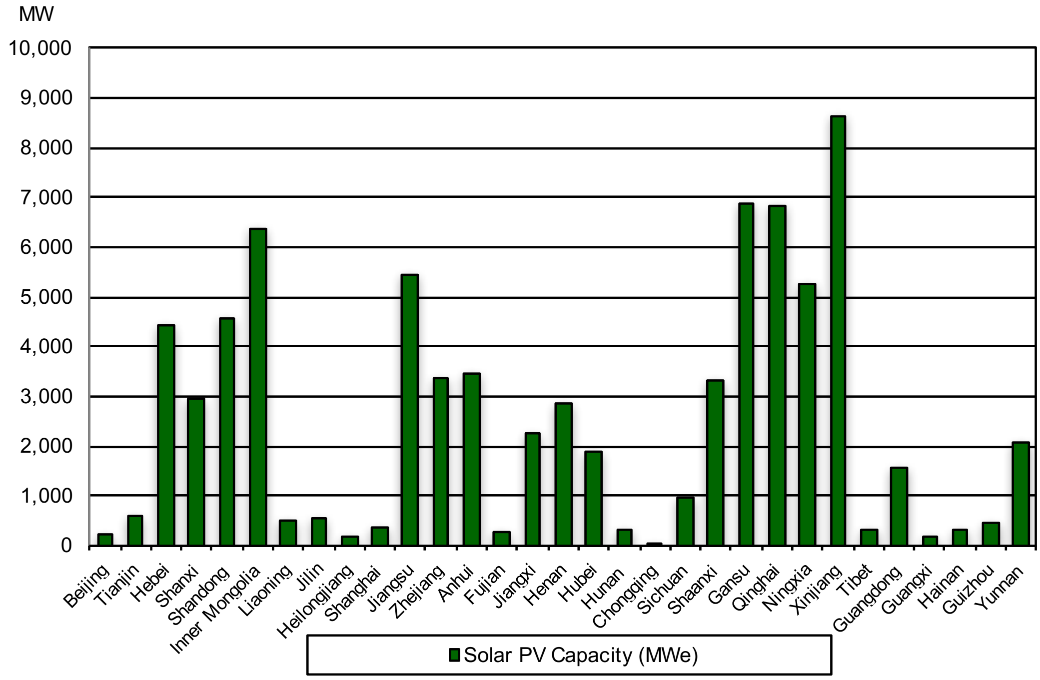


Figure 16: Solar PV Capacity by Province in 2016

Concerning curtailment, during the early days of solar PV development, most projects were located in northern and north-western China as FLH in these provinces were higher. However, rapid development and lack of grid infrastructure led to high levels of curtailment especially in Gansu, Xinjiang, and Ningxia[54]. In the first quarter of 2016 curtailment in these provinces reached 39%, 53%, and 20% respectively. As Figure 16 shows, large solar PV capacities were located in these provinces in 2016. Concerning production, in 2016 solar power produced 66.2 TWh, which for a country the size of China is not statistically relevant. However, this production is very high when compared, for example, to Germany's production of 37.5 TWh of solar power in 2016[55].

[53] China Energy Portal: 2016 PV installations utility and distributed by province
[54] DBS Asian Insights 2016: 28
[55] Fraunhofer-Institut Für Solare Energiesysteme ISE (2017): 3

China's policies for Wind and Solar PV

As part of its 13th FYP process, China has also issued specific FYPs for wind and solar PV development. In these documents, China discusses the situation of these energy sources in the country and establishes targets for deployment by the year 2020. These targets are not only established for the country as a whole (as in the case of nuclear energy, for example), but there are also provincial targets. According to the 13th FYP, by 2020 China should deploy 210 GW of wind power and 105 GW of solar PV (plus an additional 5 GW of solar thermal power).

- ***Wind power targets***

  As the latest FYP for wind energy development shows (see Table 8[56]), most of the wind capacity is to be increased in the "northern" provinces of China (see Table 8 and Figure 17 for the provinces that are included in this area). These provinces are expected to host 135 GW of wind capacity by 2020. In total, China is planning 205 GW for the whole country by 2020[57]. Taking into consideration that as of 2016 China had deployed 148 GW wind capacity for all the country, an additional 57 GW is necessary to meet these targets.

[56] China Energy Portal: 13th FYP Development Plan for Wind Power

[57] While the 13th FYP for Power Development states that 110 GW of wind power will be developed by 2020, the specific FYP for wind power refers to 205 GW of wind capacity by 2020. It is not clear why this difference exists.

Table 8: 2020 Pronvincial Wind Power Development Targets (MWe)

Other Provinces			Northern Provinces		
East China		**16,500**	**North China**		**57,500**
	Shanghai	500		Beijing	500
	Jiangsu	6,500		Tianjin	1,000
	Zhejiang	3,000		Hebei	18,000
	Anhui	3,500		Shanxi	9,000
	Fujian	3,000		Shandong	12,000
				West Inner Mongolia	17,000
Central China		**25,700**	**North-East China**		**29,000**
	Jiangxi	3,000		Liaoning	8,000
	Henan	6,000		Jilin	5,000
	Hubei	5,000		Heilongjiang	6,000
	Hunan	6,000		East Inner Mongolia	10,000
	Chongqing	500			
	Sichuan	5,000			
	Tibet	200			
South China		**27,800**	**North-West China**		**48,500**
	Guizhou	6,000		Shaanxi	5,500
	Yunnan	12,000		Gansu	14,000
	Guangdong	6,000		Qinghai	2,000
	Guangxi	3,500		Ningxia	9,000
	Hainan	300		Xinjiang	18,000
Total:		**70,000**	**Total**		**135,000**
Grand Total	**205,000**				

Figure 17: Provincial Distribution of Wind Projects

As Figure 18[58] shows, most provinces in China still need to deploy wind capacity to meet their respective targets. Most of the new capacity is necessary in Hebei (6,120 MW), Henan (4,960 MW), and Yunnan (4,630 MW). On the other hand, some provinces have even surpassed the targets such as Jilin, (+ 10 MW), Shanghai (+220 MW), and Hainan (+10 MW).

[58] Data in Table 23 in the Appendix

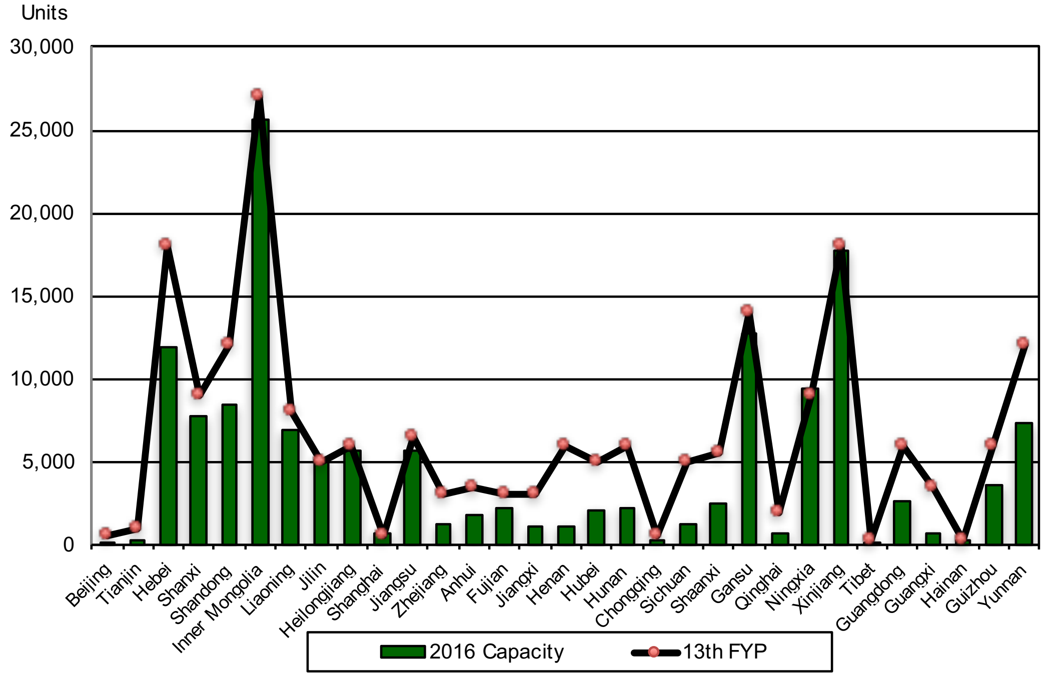


Figure 18: 2016 Wind Capacity Vs. 13th FYP Targets (MW)

- ***Solar PV targets***

Table 9[59] shows the targets that China has set for 2020. As the table shows, China aims to deploy around 100 GW of solar PV capacity. The provinces where most of this capacity is expected include Hebei, Shanxi, Inner Mongolia.

[59] China Energy Portal: 13th FYP Development Plan for Solar Energy

Table 9: 2020 Solar PV Development Targets for Key Provinces

Province	Capacity (MW)
Hebei	12,000
Shanxi	12,000
Inner Mongolia	12,000
Jiangsu	8,000
Zhejiang	8,000
Anhui	6,000
Shandong	10,000
Guangdong	6,000
Shaanxi	7,000
Qinghai	10,000
Ningxia	8,000
Total	**99,000**

Figure 19[60] shows that China still needs to deploy roughly 21 GW of solar PV capacity to meet the target outlined in the 13th FYP. The plans focuses on some specific provinces and all of them need to add more capacity, particularly Hebei, Shanxi, and Inner Mongolia.

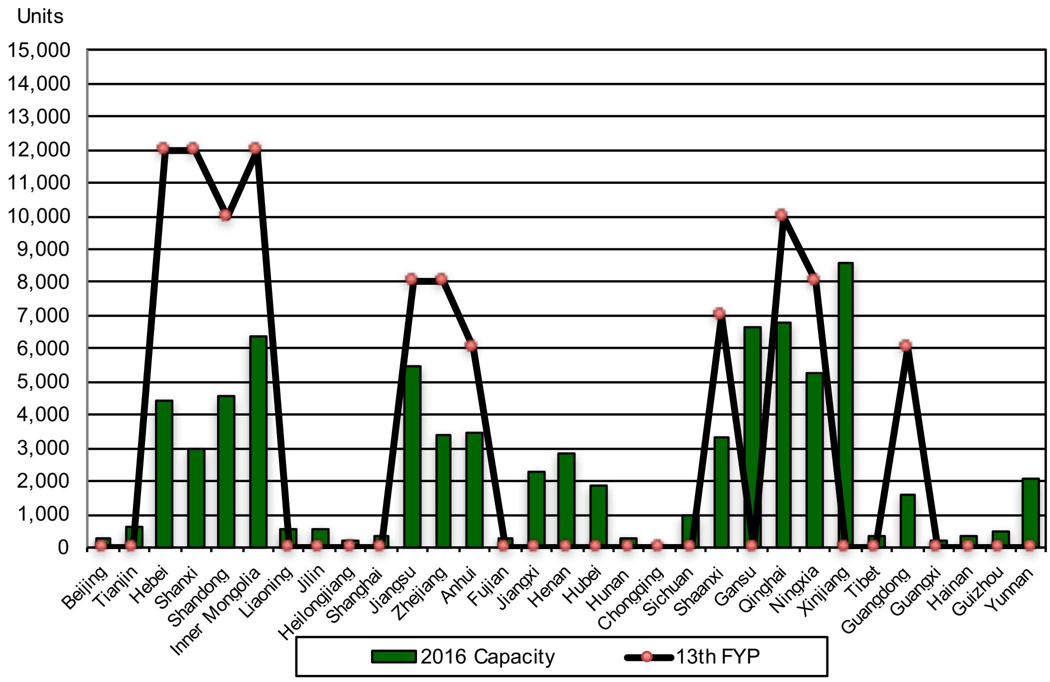


Figure 19: 2016 Solar Capacity Vs. 13th FYP Targets (MW)

60 Data in Table 23 in the Appendix

Renewable Energy Reforms

Since the start of the 2015 reforms, several additional documents dealing with wind and solar power have been issued. For example, in February 2016, the NEA issued the "Notice Related to Works for Renewable Energy Consumption in Three-North Region," which seeks to promote consumption of wind, solar, and other renewable power generated in the "Three-North" areas, which include the Northwest, the Northeast, and Huabei region[61]. In March 2017, the NEA issued the "Administrative Measures on Guaranteed Purchase of All Electricity Generated from Renewable Energy" that give priority to guarantee power generated from renewable energy sources including wind power and solar PV[62].

Table 10[63] offers an overview of some of the reforms that have been recently issued by the government:

Table 10: Reforms of the Renewable Energy Market in China

Date	Title	Results Purpose
December 2015	Notice on Improving the Benchmark Feed-in Tariff Policy for Grid Connection of Onshore Wind Power and PV Power	Established a policy that the benchmark on-grid tariffs for wind power and photovoltaic power decrease in line with the development of these two types of power sources.
March 2016	Notice on Promoting the Consumption of Wind Power in 2016	Requires local authorities to: fully understand the importance and urgency of grid connection and consumption of wind power; strictly control the construction pace of all types of power generation projects in the provinces with severe wind power curtailment; implement the policy for guaranteed purchase of all power generated from renewable energy; and actively explore the consumption channels and potentials of wind power.
March 2016	Notice on Guidance Opinions on Work for Energy Sector in 2016	Requires relevant authorities to vigorously develop non-fossil energy sources and steadily develop wind power. According to the document, China aims to promote the healthy development of the wind power sector in the "Three North" regions, and encourage faster development of wind power sector in central, eastern as well as southern regions of China. Furthermore, the document calls for efforts to solve the technical bottlenecks and institutional obstacles in the development of offshore wind power, so as to promote the healthy and sustainable development of offshore wind power.

61 Goldwind 2016: 20.
62 China Longyuan Power Group Corporation Limited 2017: 4.
63 This list is based mainly on China Longyuan Power Group Corporation Limited 2017: 27. Other sources include: China Datang Corporation Renewable Power Co, Limited 2017: 28; Huaneng Power International 2017: 4 and 19.

March 2016	Administrative Measures on Guaranteed Purchase of All Electricity Generated from Renewable Energy (Alternative translation of the document: Issuing the Measures for the Administration of the Guaranteed Buyout of Electricity Generated by Renewable Energy Resources)	Establishes the regulations for the guaranteed purchase of all power generated from renewable energy.
April 2016	Letter of Consultation Invitation of the NEA Comprehensive Department with Respect to the Notice Regarding Requirements of Establishing Assessment System on Power Generation Quota for Non-hydro Renewable Energy of Coal-fired Thermal Power Generating Unit	Power generation licenses of coal-fired power generation enterprises that fail to meet the power generation quota for non-hydro renewable energy will be revoked. By 2020, the power generation quota for non-hydro renewable energy of all coal-fired power generation enterprises in China shall account for more than 15% of the coal-fired power generation.
May 2016	Notice on Guaranteed Purchase of All Electricity Generated from Wind Power and Solar Power (Alternative Translation: Directive on the Measures for the Administration of the Guaranteed Buyout of Electricity Generated by Solar and Wind Energy Resources)	States that the minimum guaranteed purchased utilization hours of wind power and solar PV on an annual basis in the provinces with curtailment of wind power and solar PV will be determined based on the local benchmark on-grid tariffs with reference to the permitted cost plus a reasonable mark-up. Moreover, the document also puts forward the solution for failure to meet the annual minimum guaranteed purchased utilization hours, namely "to compensate the power curtailment falling within the guaranteed purchase", and specifies that it is strictly prohibited to acquire power generation rights through payments by renewable power projects to coal-fired and other power source projects in respect of the guaranteed electricity.
July 2016	Notice on Establishment of Monitoring and Early Warning Mechanism to Promote the Sustained and Sound Development of the Wind Power Industry	The early warning mechanism plays a proactive and promoting role in reasonable planning the national wind power development scheme, alleviating wind power curtailment, and implementing the policy of minimum guaranteed utilisation hours.
July 2016	Provisional Measures for Priority Dispatch of Renewable Peaking Power Generation Units	States that power grid companies and power generation companies across the country may, on a voluntary basis and through mutual agreement, specify a certain number of power generating units to serve as peak units which shall be given priority in power generation.
December 2016	Notice on Adjustments to Benchmark On-Grid Tariffs of Photovoltaic Power Generation and Onshore Wind Power Generation	This document lowers the benchmark on-grid tariffs of solar PV projects built after 1 January 2017 and onshore wind power projects obtaining construction approvals after 1 January 2018. From January 1, 2017, standard on-grid tariffs for Class I, Class II and Class III solar power zones were adjusted to 0.65 RMB/kWh ($0.10/kWh), 0.75 RMB/kWh ($0.11/kWh) and 0.85 RMB/kWh ($0.13/kWh) Benchmark tariffs for newly built onshore wind power projects (approved after 2018) in the four classes are 0.40 RMB/kWh ($0.06/kWh), 0.45 RMB/kWh ($0.07/kWh), 0.49 RMB/kWh ($0.08/kWh) and 0.57 RMB/kWh ($0.09/kWh), respectively.

China's Wind and Solar Generation Industry

In China, there are several companies that own and operate wind and solar projects. The main five power companies, which are state owned, have an important share of the wind and solar power sector capacity and generation. These producers are:

- ***China Guodian Corporation (CGC)***[64]

  China Guodian Corporation is one of the five largest integrated power generation corporations in China. It is mainly engaged in the development, operation, and management of power generation assets. By 2015, the company's total installed generation capacity reached 135 GW. This included wind power (23,030 MW), and solar PV (890 MW), hydropower (16,447 MW) as well as coal power (94,637 MW). The renewable generation accounted for 29.9% of total installed capacity in 2015.

  - An important subsidiary of Guodian is China Longyuan Power Group Corporation (Longyuan Power) that in 2016 had a wind capacity of 17,369 MW[65].

- ***China Huaneng Group (CHG)***[66]

  In the energy sector, the Huaneng Group is mainly engaged in the development, investment, construction, operation, and management of power sources. In 2016, the company had a total capacity of 165 GW.

  - An important subsidiary of the Huaneng Group is Huaneng Power International (HPI), which as of March 2017 had a generating capacity of 101,270 MW[67] in China based on a combination of hydro, wind, coal, gas and oil with fossil fuels supplying the majority of the fuel. The company's wind capacity was roughly 3,000 MW[68].

[64] Guodian Corporation. Corporate Profile
[65] China Longyuan Power Group Corporation Limited 2017:7
[66] China Huaneng Group: Company Overview
[67] Huaneng Power International 2017: 13
[68] Huaneng Power International 2017: 30.

- An additional subsidiary of the Huaneng Group is the Huaneng Renewables Energy Corporation, which in 2016 had a total capacity of 11,807 MW of which wind power was 10,252 MW and solar power was 835 MW[69].

- ***China Datang Corporation (CDC)***[70]

  Datang is involved in many business activities, including the development, investment, construction, operation and management of power energy projects. As of 2015, the company had 127 GW of installed capacity[71]. The company has two important subsidiaries.

  - China Datang Corporation Renewable Power that is mainly engaged in the development, investment, construction and management of wind power and other renewable energy sources. As of December 2016, the company's installed wind capacity was 8,345 MW and the company's solar capacity was less than 150 MW[72].

  - The other subsidiary is China Datang International Power Generation. The company's wind capacity in 2016 was 1,875 MW and solar capacity was 300 MW[73].

- ***China Huadian Corporation (CHD)***

  CHD is involved in the development of hydropower, wind power, nuclear power, solar power, as well as in gas-fired and coal power projects. By the end of 2015, CHD's total installed capacity was roughly 135 GW, with clean energy accounting for one-third of this total[74].

  - One important CHD subsidiary is Huadian Power International Corporation Limited. In 2016, the company's total controlled installed capacity was 48,139 MW, of which 42,966 MW was coal and gas power and 5,173 MW was

[69] Huaneng Renewables Energy Corporation 2017: 15
[70] China Datang Corporation. Company Profile
[71] China Datang Corporation.Installed Capacity
[72] China Datang Corporation Renewable Power Co, Limited 2017: 4.
[73] China Datang International Power Corporation 2017: 3.
[74] Huadian Corporation: Power Generation

renewable energy[75]. The company's wind capacity in 2016 was roughly 1,431 MW and solar capacity was less than 150 MW[76].

   - Another important subsidiary is Huadian Fuxin Energy Corporation Limited[77]. In 2016, the company's installed wind capacity reached 7,340 MW and solar power capacity was 977 MW[78].

- ***State Power Investment Company (SPIC)***

  SPIC is a large energy company that was the outcome of the merger between the China Power Investment Corporation and the State Nuclear Power Technology Company in 2015. In 2016, SPIC had a total installed capacity of 117 GW, including 71 GW of thermal power, 21 GW of hydropower, 4 GW of nuclear power, 11,9 GW of wind power, and 7 GW of solar power, with clean energy accounting for 42.9% of all this capacity[79].

- ***China General Nuclear (CGN)***

  CGN is a company specialized in the nuclear power market (construction and operation) with several nuclear reactors under construction and in operation with a total installed capacity of 21 GW[80]. In 2016, the company had a wind capacity of 8,600 MW and solar capacity of 1,300 MW[81].

- ***China Resources Power Holdings Ltd (CR Power)***[82]

  The company is a subsidiary of the Hong Kong-listed company, CR (Holdings) Limited. In 2016 CR Power's generation capacity was 36 GW[83]. The company's wind capacity was 5,227 MW and solar capacity was 130 MW.

As the previous section makes clear, there are several companies operating in China and developing wind and solar PV projects. They all have different levels of power capacity and some are larger than others. Table 11 summarizes the solar PV and wind capacities for the companies listed in this section. Note that the total MW numbers are just a sample of the total

[75] Huadian Power International Power Corporation 2017: 2
[76] Huadian Power International Power Corporation 2017: 3 and 4
[77] Huadian Fuxin Energy Corporation Limited. Company Profile
[78] Huadian Fuxin Energy Corporation Limited 2017: 4
[79] State Power Investment Corporation: Company Overview
[80] China General Nuclear Power. Group Profile
[81] China General Nuclear Power 2017: 16
[82] China Resources Power Holding. Corporate Profile
[83] China Resources Power Holding 2017: 8 and 9

capacity held by SOEs and deployed in China in 2015 and 2016. This indicates that in addition to the large utilities owned by the government, there are many other companies involved in the renewable energy market such as CR Power Holdings.

Table 11: Total Wind and Solar PV Capacities of Selected Utilities (2015/2016)

	Total Capacity (GW)	Wind Capacity (MW)	Solar Capacity (MW)
CGC	135	23,030	890
CHG	165	14,800	835
CDC	127	10,220	450
CHD	135	8,441	997
SPIC	117	11,982	7,118
CGN	21	8,600	1,300
CR Power	36	5,227	310
Totals	**736**	**82,300**	**11,900**

Based on information provided by some of the utilities mentioned in this section, Table 25[84] in the Appendix contains information about some of the wind projects that these utilities operate in the different Chines provinces. According to this table, in 2016 around 10 GW of wind capacity was located in Inner Mongolia followed by the Gansu province with 5 GW. Guizhou and Tibet show the lowest wind capacity deployed by these utilities with 24 MW and 5 MW respectively. These data points confirm previous observations about Inner Mongolia and Gansu being important wind hubs in China. Going forward the shifts in the investment behavior of the companies mentioned above in these and other provinces will be one indicator that will help assess the impact of the current policy changes in China's wind power sector, as these companies will most likely focus investment in provinces where the largest revenue is available

Challenges for Renewable Energy Deployment

Based on the previous discussion, two main challenges can be identified in the development of wind and solar power capacity in China.

[84] The table is based on: China Longyuan Power Group Corporation Limited 2017: 20; Huaneng Power International 2017: 30; Huaneng Renewables Energy Corporation 2017: 9 and 10; China Datang Corporation Renewable Power Co, Limited 2017: 15 and 16; Huadian Fuxin Energy Corporation Limited. Business and Distribution.

- ***Curtailment***

As the information in Figure 14 and Table 21 makes clear, China's wind power generation suffers from a serious curtailment problem that reached almost 20% in 2016. According to Datang Renewable Power and Huadian Fuxin[85], in some provinces the deployment of wind capacity did not match the expansion of grids or the demand for electricity. Therefore, there are challenges in terms of electricity transmission and consumption. As a consequence, wind projects do not produce all the power that they could at full operation. As table 21 shows, this is a serious problem for wind power in China that is leading to high curtailment and the most affected provinces in 2016 included Gansu (43% curtailment), Xinjiang (38%), Jilin (30%), and Inner Mongolia (21%). Curtailment issues are also affecting the operations and revenues of utilities. According to Datang Renewable Power[86], the company's wind projects are mainly located in "Three Northern" regions, which offer abundant wind resources. However, the electricity output of the company's wind projects is being adversely affected by the restrictions in electricity consumption and transmission in these provinces. The issue of curtailment could be addressed by a combination of strategies: improving the electricity grid, awarding renewable energy more operational hours than other power sources, reducing coal power production, or slowing down renewable energy development in affected provinces. The government is currently working on this combination of strategies to address curtailments and other challenges.

- ***Overcapacity***

As discussed in Chapter 1, China is suffering from electricity overcapacity and this may slowdown the development of renewable energy. Phasing out a number of coal plants to reduce power overcapacity and allow new and existing capacity to operate at more efficient load factors is a possible way forward to solve this issue. However, phasing out coal plants could also lead to, among other issues, rising unemployment in the provinces where coal plants or coal mines are located. This could, therefore, prove politically difficult for the central government to accomplish. Nevertheless, taking into consideration the FYP for 2020, it appears China will further add coal and

[85] China Datang Corporation Renewable Power Co, Limited 2017: 22; Huadian Fuxin Energy Corporation Limited (2017): 48.
[86] China Datang Corporation Renewable Power Co, Limited 2017: 23

other power sources to its electricity mix regardless of overcapacity in the electricity market. Therefore, it is not clear how these challenges will be addressed unless the country sees a higher level of power demand in the coming years.

- ***Financial issues***

  In general, from a financial perspective, China has not had major challenges in the past in deploying power capacity based on any source. Most remarkably, China's nuclear energy program has deployed a large number of nuclear reactors in a short period of time and, although at a slower pace, more reactors are planned by 2020. For many years, it has been considered that money is not an issue for Chinese power companies when it comes to, for example, building nuclear power plants, and it is likely that this is still the case as there is strong government support for the power sector. However, many of the companies investing in solar and wind projects are now publicly traded companies that have shareholders to respond to when it comes to investment decisions. If in the past SOEs were not worried much about investments and rates of return as they enjoy the full support of the Chinese government in case of financial losses, it appears that their publicly traded subsidiaries are now taking investment decisions taking into consideration financial factors. The Chinese government will most likely still support its SOEs and the publicly traded subsidiaries, but an additional layer of difficulty has been added to the development of the power sector by opening up to supply and demand dynamics in a country that is still heavily regulated by the central government.

Summary

As this section has shown, solar and wind projects are located all over the country, although there are clusters of activity in certain provinces. A combination of resources (i.e. solar radiation or wind speed), operational hours, and FiT will determine the future development of wind and solar electricity in these provinces. Moreover, the government has issued and is issuing legislation to achieve a number of related goals:

- Increase the role of renewable energy in the country
- Reduce curtailment
- Reduce FiT costs

Based on the different policy elements, the utilities will respond to market incentives contained in legislation and make required investments in the provinces. As this new round of policy changes have just started in 2015 with additional legislation issued in 2016, it is difficult to assess for now how utilities are responding to the new regulatory framework. The year 2017 may bring more clarity about any changes in investments based on the last round of policy changes.

7. The Economics of Renewable Energy: Wind and Solar PV[87]

Chapter 7 will discuss three areas, namely the FiT system for the development of wind power and solar PV in China, the LCOE of these power sources based on existing literature, and the LCOE using the author's own calculations.

Financial Support for Wind and Solar PV Development

Feed-in-Tariffs (FiT) have been a key policy instrument for the development of renewable energy in many countries as it has provided incentives for investors to commit financial resources in the face of, most likely, low operational hours when compared to other sources. The results of this policy have been impressive in terms of developing capacity, but also negative in terms of costs of electricity for consumers, as FiT is financed from the public purse. China has also used FiT to develop renewable energy and this has been adjusted with increasing power development. The last modification, a reduction, took place in December 2016 and future developments will tell if FiT will go up or down in the next round of policy decisions.

Wind Feed-in Tariffs

As explained in Chapter 4, FiT can be defined as the price of electricity per kWh for which a power project sells generated electricity to power grid companies. These tariffs include:

1. A benchmark or approved FiT;
2. Tariff premiums for wind power companies to compensate the costs of transmission lines that wind power companies constructed and owned (if applicable); and/or
3. Discretionary tariff subsidies granted by the local government (if applicable)

This definition suggests that 1) there is a base FiT that could change with additional government payments, 2) FiTs vary from province to province. And 3) there are FiT differences also within provinces, as projects could be located in the different wind or solar zones that exist in China.

Data provided by Huaneng Power International (HPI) helps to illustrate these characteristics. Figure 20 (based on Table 26[88] in the Appendix) shows different HPI

[87] The exchange rate used in this section is RMB 1 = $0.15 (as of October 3, 2017)

wind projects located in various provinces in China. The data makes it clear that there are not only differences in average FiT among provinces, but also among projects in the same province. In 2016, the highest FiT for HPI's wind projects were located in Shandong province (in the range of 630 RMB/MWh - 640 RMB/MWh or $96.52/MWh - $98.05/MWh) followed closely by the Heilongjiang province (630 RMB/MWh or $96.52/MWh). The lowest FiT achieved by HPI in 2016 was in Inner Mongolia (520 RMB/MWh or $79.66/MWh). Moreover, in Gansu there were four different FiT for four different HPI projects.

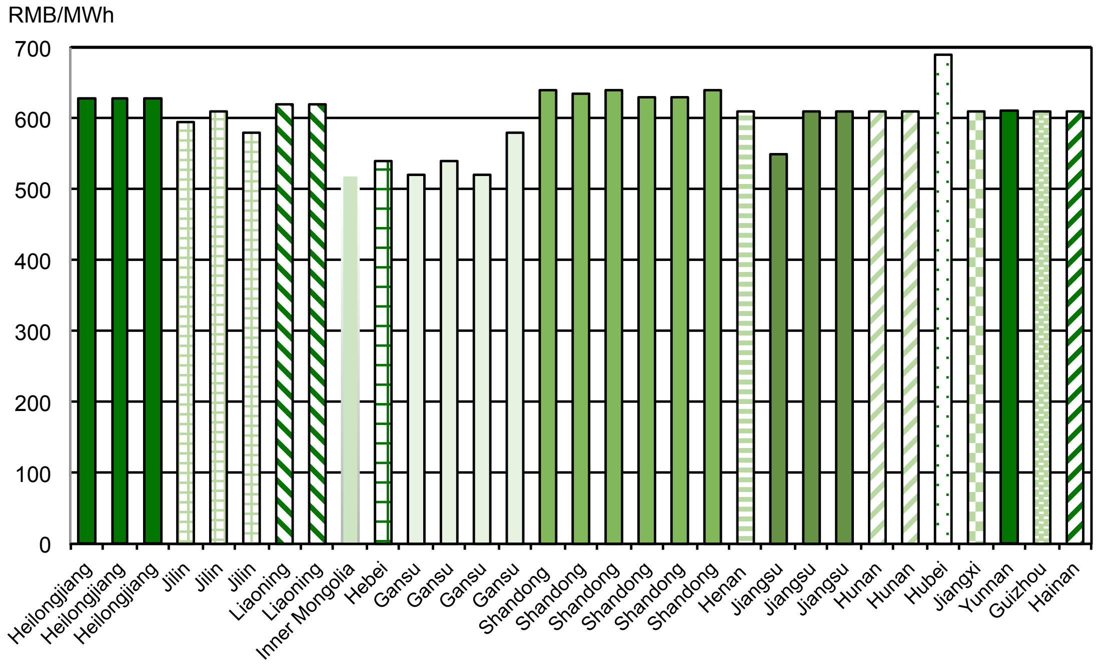


Figure 20: HPI 2016 Average FiT for Wind (all provinces)

In Figure 21[89], some provinces have been selected to further illustrate these differences. Figure 21 clearly shows that there are different FiT for wind projects located in Liaoning, Hebei, Gansu, Jiangsu, and Inner Mongolia. Moreover, the figure contains three HPI projects located in the Gansu province: Yumen, Jiuquan, and Jiuquan II. Since 2014 all these projects have had different levels of FiT although they have been located in the same province.

[88] Huaneng Power International 2017: 21
[89] Data in Table 26 in the Appendix

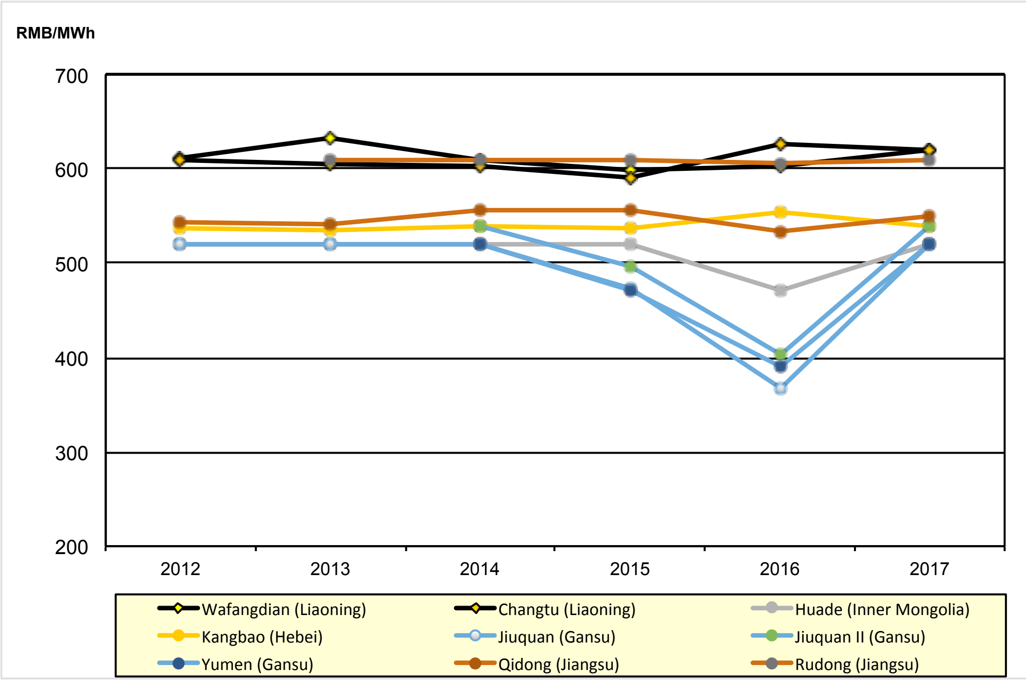


Figure 21: HPI 2016 Average FiT for Wind (selected provinces)

Figure 21 also shows that between 2014 and 2016, the FiT for the projects in the Gansu province saw a reduction, but went up again in 2017 (the reason why there is data for 2017 is because the FiT is set several years in advance). There were also reductions in the other provinces, but the changes were not as dramatic as in Gansu. The reduction in FiT from 2015 to 2016 is also confirmed by China Longyuan, whose average FiT went from 591 RMB/MWh ($90.54/MWh) in 2015 to 570 RMB/MWh ($87.32/MWh) - VAT inclusive in 2016[90]. Moreover, according to Huadian Fuxin, the company's FiT (tax exclusive) for wind projects in 2016 was 459.5 RMB/MWh ($70.40/MWh), representing a decrease of 35.9 RMB/MWh ($5.50/MWh) compared to 2015[91].

Solar PV Feed-in Tariffs

Table 12 contains data for HPI's FiT for solar PV projects in 2016. Due to the small number of data points, the data does not allow for many observations except for the fact that these solar PV projects have received higher FiT than wind projects. There are differences in the tariffs for the different provinces, but as the data covers up to two years, it does not allow any trends to be identified. In this context, Hudian Fuxin reported that

[90] China Longyuan Power Group Corporation Limited 2017: 11
[91] Huadian Fuxin Energy Corporation Limited 2017: 40

the company's average FiT (tax exclusive) in 2016 for solar projects was 837.9 RMB/MWh ($128.37/MWh), which is 61.3 RMB/MWh ($9.39/MWh) lower compared to 2015[92]. This decrease can be observed for some HPI projects in Zhejiang and Hainan.

Table 12: HPI's Solar Power Average Tariff in RMB/MWh ($/MWh) in 2016 (VAT inclusive)

Province	Wind Project	2014	2015	2016	2017
Liaoning					
	Dandong			950 (145.54)	950 (145.54)
Hebei					
	Kangbao			784.95 (120.25)	982.50 (150.52)
Shandong					
	Boshan				1,000 (153.20)
	Sishui				1,200 (183.84)
	Gaozhuang				1,000 (153.20)
Zhejiang					
	Changxing			1,208 (185.07)	1,100 (168.52)
	Hongqiao			980 (150.14)	980 (150.14)
Guangdong					
	Shantou			980 (150.14)	980 (150.14)
Hainan					
	Dongfang			1,010 (154.73)	1,000 (153.20)

Feed-in Tariff Policies

- ***Wind Power***

Confirming the observations in Figures 20 and 21, Table 13[93] shows the differences in FiT for wind power among provinces and within provinces. The reason for these differences is that there are four zones for determining FiT for wind projects in the country. This determination is somehow flexible as one area

[92] Huadian Fuxin Energy Corporation Limited 2017: 41
[93] DBS Research Group 2017: 5

(e.g. an entire province or an area within a province) that belonged to a specific zone during a certain period could be part of another zone in another period. For example, in December 2016 the government reclassified Yunnan to Zone II from Zone IV for new projects approved to start in 2018. This is because Yunnan is ranked China's top four in terms of utilisation hours in 2016 (22.223 FLH; See Table 21). Also, Table 13 shows that areas in the same province could belong to different zones, as is the case of, for example, Gansu.

Moreover, as stated in Table 10, in December 2016 the Chinese government issued a "Notice on Adjustments to Benchmark On-Grid Tariffs of Photovoltaic Power Generation and Onshore Wind Power Generation". In summary, this document lowers the benchmark FiT of solar PV projects built after 1 January 2017, and onshore wind power projects obtaining construction approvals after 1 January 2018.

Table 13 also shows that the December 2016 FiT changes have led to lower FiTs for projects receiving approval after 2018 when compared to projects approved before this date. Also, the new FiT is lower than those outlined by the NDRC in 2015. These lower FiTs could be the result of a number of causes: 1) the government may aim at slowing down the development of wind power where there is, for example, high curtailment (e.g. Inner Mongolia, Gansu, Xinjiang); 2) the government is providing more incentives to further expand wind power in provinces that are less developed in terms of wind capacity; 3) the government is promoting more development in provinces with good operational hours (e.g. Yunnan); or 4) the government is trying to reduce the costs of FiT.

Table 13: Recent Changes in China's FiT for Wind Power (On-shore)

FiT Adjustment Policy Announced by NDRC in December 2016 RMB/kWh ($/kWh)							FiT cut Announced by NDRC in Dec. 2015
Zone	**Approval by 2015 and Operation Started Before 2016**	**Approval by 2015 and Operation Starts after 2016**	**Approval by 2015 and Const. Starts Before 2018**	**Approval by 2016 and Const. Starts After 2018**	**Approval After 2018***	**Areas**	**Approval After 2018***
I	0.51 (0.08)	0.49 (0.08)	0.49 (0.08)	0.47 (0.07)	0.40 (0.06)	**Inner Mongolia (West)** (except Chifeng, Tongliao, Xinganmeng, Hulunbeier), **Xinjiang** Urumqi, Yilihasake, Changji Huizu, Kelamayi, Shihez	0.44 (0.07)
II	0.54 (0.08)	0.52 (0.08)	0.52 (0.08)	0.50 (0.08)	0.45 (0.07)	Zhangjiakou and Chengde of **Hebei**; Chifeng, Tongliao, Xinganmeng, Hulunbeier of **Inner Mongolia (East)**; Zhangye, Jiayuguan and Jiuquan of **Gansu**	0.47 (0.07)
III	0.58 (0.09)	0.56 (0.09)	0.56 (0.09)	0.54 (0.08)	0.49 (0.08)	Baicheng, Songyuan of **Jilin province**; Jixi, Shuangyashan, Qitaihe, Suihua, Qichun, Daxinganling of **Heilongjiang**; **Gansu** (except Zhangye, Jiayuguan and Jiuquan); **Xinjiang** Uyghur Autonomous Region (except Urumqi, Yilihasake, Changji Huizu, Kelamayi, Shihezi) and Ningxia	0.51 (0.08)
IV	0.61 (0.09)	0.61 (0.09)	0.61 (0.09)	0.60 (0.09)	0.57 (0.09)	Remaining provinces **(Yunnan is included as Zone II for projects approval after 2018)**	0.58 (0.09)

*Note: The projects denote i) new approval starting in 2018, ii) new approval before 2018 but project not started by 2019.

- ***Solar Power***

  Table 14[94] contains the FiT for solar projects before the December 2016 Notice that, as explained before, reduced the tariffs. As the table shows, there are three FiT zones for solar PV in China and some provinces host different FiT zones. The higher tariffs are located in Zone III with the lowest in Zone I. Table 14 also shows that solar PV tariffs are higher than those for wind power plants. Based on the Notice of December 2016, from January 1, 2017 FiT for solar projects were adjusted to 0.65 RMB/kWh or $0.10/kWh (Zone I), 0.75 RMB/kWh or $0.11/kWh (Zone II) and 0.85 RMB/kWh or $0.13/kWh (Zone III), which represent decreases of between 0.15 RMB/kWh and 0.13 RMB/kWh when compared to previous FiTs for solar power.

Table 14: Solar FiT 2016

Zone	Tariff RMB/kWh ($/kWh)	Provinces (Regions)
I	0.9 > 0.8 (0.14 > 0.12)	Ningxia, Qinghai Haixi, Gansu Jiayuguan, Wuwei, Zhangye, Jiuquan, Dunhuang, Jinchang, Xinjiang Hami, Tacheng, Altay, Karamay, Inner Mongolia region not especified in Zone II
II	0.95 > 0.88 (0.15 > 0.13)	Beijing, Tianjin, Heilongjiang, Jilin, Liaoning, Sichuan, Yunnan, Inner Mongolia (Chifeng, Tongliao, Xinganmeng, Hulun Buir), Hebei (Chengde, Zhangjiakou, Tangshan, Qinghuangdao), Shanxi (Datong, Shuozhou, Xinshou), Shaanxi (Yulin, Yanan), Qinghai (excluding regions in Zone I), Gansu (excluding regions in Zone I), Xinjiang (excluding regions in Zone I)
II	1 > 0.98 (0.15 > 0.15)	Regions not specified under Zone I or Zone II

Summary

This section has helped illustrate the complexity of the FiT system in China. The fact that there are different FiT zones for wind and solar PV - and sometimes regions in the same province belong to different zones - adds an additional level of difficulty for analysis. This complexity will be further discussed in the next section.

Localized Cost of Electricity: Reviewing the Literature

In order to discuss the economics of wind and solar power in China, the LCOE indicator will be used as this allows comparing projects in different provinces in China.

[94] DBS Asian Insights 2016: 26

As mentioned in the introduction, for this assessment, one available study will be consulted to compare LCOE for wind and solar power (and also coal) as other recent studies comparing these two sources using similar methodologies have not been found. This study is entitled "Could Wind and PV Energies Achieve the Grid Parity in China until 2020?"[95], and will be referred to as "Analysis 1".

Moreover, another study will be used to further discuss LCOE, but this study discusses only wind power. This study, referred to as "Analysis 2", is entitled "The Economics of Wind Power in China and Policy Implications"[96] and has the goal of determining LCOE for wind power projects.

Another study will be used, Analysis 3, which compares the LCOE of nuclear and wind power. The LCOE about wind energy will be used for comparison with Analyses 1 & 2.

The Levelized Cost of Electricity

In 2015, the International Energy Agency (IEA) and the Nuclear Energy Agency (NEA) published a report entitled "Projected Costs of Generating Electricity" (2015 Edition), which "examines in depth the LCOE generation for all main electricity generating technologies"[97] The report discusses, among others, the LCOE concept, offers an overview of different generation technologies and their costs, provides country data on generation costs, and offers a look into the future of projected costs of electricity.

According to the report, the LCOE:

> *"is calculated by summing all plant-level costs (investments, fuel, emissions, operation and maintenance, dismantling, etc.) and dividing them by the amount of electricity the plant will produce, after an appropriate discounting. The LCOE represents the average lifetime cost for providing a unit of output (MWh) for a given capacity factor, often the average capacity factor achievable by the power plant or a common value typical of baseload plants."*[98]

[95] Hong Lia, Yang Yu, Yuantao Xie, Jing Zhang 2016
[96] Zifa Liu, Wenhua Zhang, Changhong Zhao, and Jiahai Yuan 2015
[97] IEA/NEA 2015: Foreword
[98] IEA/NEA 2015: 163

Analysis 1

One goal of this analysis is "to examine and forecast the cost development of wind and solar power in China during 2014–2020."[99] The study reviews first the existing analyses concerning costs development of wind, solar, and coal and explains the different factors that affect the costs. Next, the authors explain the methodology for calculating LCOE, which includes some modifications when compared to other methods of calculating LCOE for wind, solar, and coal.

Concerning data to be used for calculating LCOE, the authors used a combination of domestic and international data as, for example, not all cost data is available for wind and solar projects in China. Also, it is important to note that cost data is based on information and statistics published by 2014.

For wind power the authors used cost data available from several sources, including the China Wind Energy Association (e.g. wind turbine costs and technical operation), the World Bank (e.g. steel prices), and the China Renewable Energy Engineering Institute (e.g. construction and installation engineering costs). The authors also used cost data on solar power available from sources including the International Energy Agency (e.g. PV module prices) and specialized publications (e.g. polysilicon prices, silicon thickness, cell efficiency data). Finally, for coal power the data was collected mainly from government agencies such as the NDRC.

For the purposes of this analysis, the results related to LCOE are presented below.

- ***Results***

LCOE Wind

The results concerning LCOE for wind power are presented in Table 15[100]. Note that the FiT to calculate this LCOE is the same as the FiT contained in Table 13: "Approval by 2015 and operation started before 2016". According to the authors, the levelized price of wind power ranges in 0.50 - 0.63 RMB/kWh ($0.08/kWh - $0.10 kWh), depending on the different resource, construction, and curtailment conditions. Moreover, they explain that the levelized price is higher than expected in wind bases

[99] Hong Lia, Yang Yu, Yuantao Xie, Jing Zhang 2016: 4173.
[100] Hong Lia, Yang Yu, Yuantao Xie, Jing Zhang 2016: 4182

located in China's northern areas where the wind curtailment rate can exceed 20%[101]. Table 15 indicates that the current FiT is barely adequate to cover the LCOE of wind plants in resource Zones I, II and III.

Table 15: FiT and LCOE for Wind Power in China (Analysis 1)

Wind Zones	Annual EUH	FiT RMB/kWh ($/kWh)	LCOE RMB/kWh ($/kWh)	Areas
I	>3,000	0.51 (0.08)	0.5-0.54 (0.08-0.08)	Inner Mongolia (except Chifeng, Tongliao, Hinggan League and Hulun Buir), Xinjiang (Urumchi, Ili Kazak Autonomous Prefecture, Changji Hui Autonomous Prefecture, Karamay and Shihezi)
II	2,500-3,000	0.54 (0.08)	0.57-0.63 (0.09-0.10)	Hebei (Zhangjiakou and Chengde), Inner Mongolia (Chifeng, Tongliao, Hinggan League and Hulun Buir), Gansu (Zhangye, Jiayuguan and Jiuqua)
III	2,000-2,500	0.58 (0.09)	0.54-0.63 (0.08-0.10)	Jilin (Baicheng and Songyuan), Heilongjiang (Jixi, Shuangyashan, Qitaihe, Suihua, Yichun and Daxinganling), Xinjiang (except Urumchi, Ili Kazak Autonomous Prefecture, Changji Hui Autonomous Prefecture, Karamay and Shihezi), Ningxia
IV	<2,000	0.61 (0.09)	<0.61 (<0.09)	Other areas

LCOE Solar PV

The results concerning LCOE for solar power are presented in Table 16[102]. Note that the FiT data in Table 16 are the same as those contained in Table 14, which was still valid in 2016. According to the authors, the levelized price of solar power ranges in 0.8 - 1.01 RMB/kWh ($0.12/kWh - $0.15 kWh), depending on the different resources, construction, and technological conditions. Moreover Table 16 shows that the current FiT is high enough to cover the LCOE of PV plants in the three different zones.

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[101] Hong Lia, Yang Yu, Yuantao Xie, Jing Zhang 2016: 4182
[102] Hong Lia, Yang Yu, Yuantao Xie, Jing Zhang 2016: 4183

Table 16: FiT and LCOE for Solar Power in China (Analysis 1)

Irradiation Zones	Annual EUH	FiT RMB/kWh ($/kWh)	LCOE RMB/kWh ($/kWh)	Areas
I	>1,600	0.9 (0.14)	0.8-0.85 (0.12-0.13)	NX, QH (Haixi), GS (Jiayuguan, Wuwei, Zhangye, Jiuquan, Dunhuang, Jinchang), XJ (Kumul, Tacheng, Altay, Karamay), IM (except Chifeng, Tongliao, Hinggan League and HulunBuir)
II	1,400-1,600	0.95 (0.15)	0.8-0.9 (0.12-0.14)	BJ, TJ, HLJ, JL, LN, SC, YN, IM (Chifeng, Tongliao, Hinggan League and HulunBuir), HB1 (Chengde, Zhangjiakou, Tangshan, Qinhuangdao); SX1 (Datong, Shuozhou and Xinzhou), SX2 (Yunlin and Yanan), QH, GS, Other XJ areas
III	1,000-1,400	1 (0.15)	0.9-1.01 (0.14-0.15)	Other areas

LCOE Coal

Unfortunately, the study does not provide any detailed information about coal LCOE, but states:

> *"that the LCOE is CNY 0.34/kWh in 2013 under the national average annual operation hours and will rise slightly to CNY 0.36/kWh in 2020 under the similar operation hours."*[103]

In summary, the results of the study demonstrate that wind and solar PV power costs are uncompetitive to that of coal-fired power both in terms of national average costs and the costs in provincial areas (based on 2013 data). The authors forecast that by 2020, the LCOE for wind and solar in half of provinces with resource conditions (e.g. less curtailment, more FLH) and higher electricity prices will fall at or below the grid parity. Moreover, if environmental external costs for coal plants are accounted, both wind and solar power can achieve grid parity much earlier. The authors note that the resolution of the wind curtailment problem can extensively improve the cost competitiveness of wind plants in north China.

[103] Hong Lia, Yang Yu, Yuantao Xie, Jing Zhang 2016: 4183

Analysis 2

The authors of this study started reviewing the literature concerning the use of FiT as a tool for developing renewable energy and also the development of wind power in China. Next, the methodology to assess the LCOE is presented, which is called the E3 model. According to the authors:

> *"The E3 model is based on a detailed representation of generator's cash flows that includes technology and fuel characteristics, operation and maintenance cost, pollutant control and emissions cost and incurred taxes."*[104]

Moreover, the authors explain the variables and factors that will be used for the LCOE calculation, which include capital expenditures (e.g. turbine costs, land costs, etc.), financial variables (e.g. interest rates, depreciation rates, etc.), operating expenditures (e.g. O&M costs), capacity factors, taxes, and other variables. It is important to note that Analysis 2 only contains data references until 2013.

- ***Results***

The results of these calculations are presented in Tables 17 and 18[105]. As the tables show, the authors of the study assume a reduction in investment costs from 2015 to 2020 for all wind zones. Furthermore, Scenario 5 is considered the worst-case scenario in both cases as it has low operational hours, fewer operational years, and a high maintenance rate. The LCOE for all scenarios falls by 1 cent from 2015 to 2020 except for in Scenario 1, which remains the same at 0.29 RMB/kWh ($0.04/kWh).

Table 17: Estimated LCOE of Wind Power in China for 2015 (Analysis 2)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Investment (RMB/kWh)	4,600[106]	4,600	4,600	4,600	4,600
Annual operation (hours)	2,500	2,300	2,100	1,900	1,900
Service Life (Years)	20	20	20	20	15
Depreciation (Years)	15	15	15	15	10
Maintenance Rate	2%	2%	2%	2%	4%
Wind Power LCOE (RMB/kWh) ($)	0.29 (0.04)	0.32 (0.05)	0.35 (0.05)	0.38 (0.06)	0.46 (0.07)
Wind Zone	I	II	III	IV	IV

[104] Zifa Liu, Wenhua Zhang, Changhong Zhao, and Jiahai Yuan 2015: 1531.
[105] Zifa Liu, Wenhua Zhang, Changhong Zhao, and Jiahai Yuan 2015: 1539. The FiT for wind used for these calculations are the same as the FiT contained in Table 13: "Approval by 2015 and operation started before 2016" (i.e. the same FiT used in Analysis 1 in Table 15): Zone I: 0.51 RMB/kWh; Zone II: 0.54 RMB/kWh; Zone III: 0.58 RMB/kWh; and Zone IV: 0.61 RMB/kWh)
[106] $704.72/kWh

Table 18: Estimated LCOE of Wind Power in China for 2020 (Analysis 2)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Investment (RMB/kWh)	4,400[107]	4,400	4,400	4,400	4,400
Annual operation (hours)	2,500	2,300	2,100	1,900	1,900
Service Life (Years)	20	20	20	20	15
Depreciation (Years)	15	15	15	15	10
Maintenance Rate	2%	2%	2%	2%	4%
Wind Power LCOE (RMB/kWh) ($)	0.29 (0.04)	0.31 (0.05)	0.34 (0.05)	0.37 (0.07)	0.45 (0.07)
Wind Zone	I	II	III	IV	IV

Analysis 3: Comparing Wind and Nuclear

An additional analysis covering the LCOE for wind projects has been prepared by DBS Insights, a publication of the Development Bank of Singapore. This analysis compares wind and nuclear LCOEs and was prepared based on 2015 data. However, the analysis does not have the level of detail as the previous study and does not present results by wind zones. The results are provided in Table 19[108]. As Table 19 shows, the LCOE for wind is 0.35 RMB/kWh ($0.05/kWh) compared to 0.204 RMB/kWh ($0.03/kWh) for nuclear. Therefore, nuclear energy is more competitive. On the other hand, wind LCOE in this study is lower than the different LCOE scenarios shown in Tables 15, 17, and 18. As there is no explanation about the LCOE methodology used in the DBS report, it is not possible to determine what the main differences are compared to the other analyses.

[107] $674.08/kWh
[108] DBS Asian Insights 2016: 47

Table 19: LCOE for Nuclear and Wind Power Based on 2015 Statistics (Anaylsis 3)

	Wind Power	Nuclear Power
Cumulative Installed capacity (GW)	145	27
Project design life (year)	20	40
Unit capex (RMB/kW)	7,180-8,580[109]	12,000[110]
Average lead time of construction completion (year)	0.75-1.0	5
Equity share (%)	20	20
Cost of debt (%)	5.40	4.50
Unit depreciation & amortization (RMB/kWh)	0.216	0.052
Unit fuel cost (RMB/kWh)	0	0.057
O&M (RMB/kWh)	0.011	0.017
LCOE (RMB/kWh) ($)	0.35 (0.05)	0.204 (0.03)

Summary

In order to summarise the results for the LCOE of wind power reviewed in the previous sections some observations are necessary.

First, the input data for these analyses varies as Analysis 1 stated that it used data until 2014, Analysis 2 contains figures until 2013, and Analysis 3 stated it used statistics as of 2015 to calculate the LCOE. Also, one difference between Analysis 1 and Analysis 2 is the number of operational hours assigned to each wind zone. Therefore, there are different data inputs (e.g. different costs) and this fact leads to different results and does not allow for a sound comparison.

Second, Analysis 1 and 2 used different methodologies to calculate the LCOE as they use some input data that other analyses may not have used. Analysis 3 does not provide any information on how the LCOE is calculated. These differences also make comparing the different studies difficult.

Third, Analysis 1 and Analysis 2 specified the FiT they use for the LCOE calculation, while Analysis 3 does not specify this. However, it is expected that Analysis 3 used the same FiT data, as this was the last FiT available for the year 2015. Moreover, Analysis 2 provides a forecast of the LCOE by 2020, but as FiT were reduced in

[109] $1,099-$1,314

[110] $1,838; One possible reason for this low capex for nuclear reactors could be that DBS included in its analysis the domestic reactors that have been built in China so far and that were considered Generation II+. The costs of these designs are lower than the imported Generation III designs that have been built in China so far. China is not building Generation II+ reactor designs anymore.

December 2016, this forecast is now irrelevant. New LCOE calculations are necessary in order to reflect the latest FiT reduction and forecast the LCOE by 2020.

Finally, while Analysis 1 and 2 provide LCOE for the four wind zones in China, Analysis 3 does not provide this information. It appears the results of Analysis 3 represent a national average as a single value is presented. However, it is not clear if this is the case.

The following Table 20 presents the LCOE based on these three studies for wind power. For Analysis 2, Scenario 4 of Zone IV (see Table 17) is used, as this is the best-case scenario for this zone (0.38 RMB/kWh or $0.06/kWh vs. 0.46 RMB/kWh or $0.07/kWh).

Table 20: Comparing Wind Power LCOE RMB/kWh ($/kWh)

	Analysis 1	Analysis 2	Analysis 3
Zone I	0.5-0.54 (0.08-0.08)	0.29 (0.04)	0.35 (0.05)
Zone II	0.57-0.63 (0.09-0.10)	0.32 (0.05)	0.35 (0.05)
Zone III	0.54-0.63 (0.08-0.10)	0.35 (0.05)	0.35 (0.05)
Zone IV	<0.61 (<0.09)	0.38 (0.06)	0.35 (0.05)

Table 20 shows that the results of Analysis 1 (published in 2016) indicate a higher LCOE than the other two studies. Analysis 2 (published in 2015) has a lower LCOE for all wind zones, which are closer to the LCOE calculated by Analysis 3. Comparing these LCOEs to the one for coal (reported in Analysis 1), it is clear that all studies report a higher LCOE than coal (0.34 RMB/kWh or $0.34/kWh in 2013). The LCOE for nuclear contained in Analysis 3 (0.204 RMB/kWh or $0.03/kWh is based on 2015 data) is also lower than the LCOE calculated for wind power in all three analyses. An additional round of calculations based on 2016 data and the related policy reforms is necessary to reassess the competitiveness of wind power with other power sources such as coal and nuclear power.

LCOE Assessment

In this section, the LCOE will be discussed based on the author's own assessment. The formula for the LCOE value is as follows:

$$LCOE = \left(C\ fuel + \frac{C\ O\&M}{H} * 1000\right) + \frac{1000 * I * CRF}{H}$$

$$CRF = \frac{r * (1 + r)^t}{(1 + r)^t\ - 1}$$

Where:

C fuel: Fuel costs per energy unit [$/MWh]

C O&M: Operation and maintenance costs per energy unit [$/(kW/year)]

I: Investment costs per kW [$/kW]

H: Full-load hours [h/year]

CRF: Capital Recovery Factor:

r: Interest rate (weighted average cost of capital)

t: Lifetime/Payback time of the plant (year)

Some of the inputs to be used in this formula come from the 2015 IEA/NEA report about Generation Costs:

- Lifetime of wind and solar projects: 25 years[111]
- Investment Costs (3%) for solar PV (200 MW ground mounted): $970/kW[112]
- Investment Costs (3%) for Onshore Wind (50 MW): $1,243/kW[113]
- These investment costs have been adjusted for 2016[114]

Other data include:

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[111] IEA/NEA 2015: 30
[112] IEA/NEA 2015: 43
[113] IEA/NEA 2015: 44
[114] CPI Inflation Calculator (December 2015 adjusted to December 2016)

- FLH for wind power are contained in table 21 and reflect 2016 statistics
- The FLH for solar PV are contained in Table 27 and reflect guaranteed hours that the Chinese government has provided to solar PV projects in specific provinces

Finally, the cost of capital for both wind and solar projects has been set at 7% and O&M costs for wind power have been set at 3% and for solar PV at 1% (% of total costs)

- ***Solar PV***

  For solar power, data in Table 27 shows the guaranteed utilization hours for solar PV in two resources zones. For Zone I, the guaranteed operational hours are 1,500 hours. For Zone II, the guaranteed hours range between 1,300 and 1,450. The higher end in Zone II will be used to calculate the LCOE as this is the best-case scenario.

  Based on the data contained in Tables 28 & 29, the results for the LCOE are:

  - Zone 1: $61.9 MWh ($0.06/kWh or $6.2 c/kWh)
  - Zone II: $64 MWh ($0.06/kWh or $6.4 c/kWh)

  As the results show, in terms of the LCOE, higher guaranteed hours make solar PV projects in Zone I slightly more competitive than in Zone II. If technically possible, the increase of FLH in these two zones would lead to the lower LCOE and, therefore, increase the competitiveness of solar PV in both zones.

  It is not possible to make a one-to-one comparison between these LCOE results and those shown is Table 16 in Analysis 1, as the calculations are based on different assumptions. However, the LCOE results here are substantially lower than those in Analysis 1 ($0.06/kWh here Vs. $0.12/kWh- $0.15/kWh in Table 16). It is unclear why there is such a major difference between the results of Analysis 1 and the assessment in this section. Nevertheless, it is worth noting that the IEA reports a LCOE of $54.84/MWh[115] for solar PV (200 MW – ground mounted), which is closer to the LCOE results in this section than to those in Table 16.

  Some common ground between Analysis 1 and this analysis can be found in two instances. Firstly, Table 16 shows that the LCOE for solar PV in the areas located in Zone I is slightly lower than those in Zone II. The results here indicate the same case.

[115] IEA/NEA 2015: 50 and 51.

Secondly, Table 16 indicates that the existing FiT for solar PV can cover the LCOE results reached in Analysis 1, which is also the case for the LCOE results in this section.

- ***Wind Power***

In order to assess the wind power LCOE, the provinces where there is a high level of curtailment have been selected (the list is contained in Table 21), as there is a lot of potential for higher FLH in these provinces if curtailment is reduced. The data inputs for the calculations are contained in Tables 30 and 31. The LCOE results for these provinces are (in ascending order):

  - Yunnan: $64.7 MWh ($0.06/kWh or $6.47 c/kWh)
  - Liaoning: $74.6 MWh ($0.07/kWh or $7.46 c/kWh)
  - Shaanxi: $73.7 MWh ($0.07/kWh or $7.37 c/kWh)
  - Hebei: $69.3 MWh (or $0.07/kWh or $6.93 c/kWh)
  - Shanxi: $74.3 MWh ($0.07/kWh or $7.43 c/kWh)
  - Inner Mongolia: $78.6 MWh ($0.08/kWh or $7.86 c/kWh)
  - Heilongjiang: $84.4 MWh ($0.08/kWh or $8.4 c/kWh)
  - Ningxia: $92.6 MWh ($0.09/kWh or $9.26 c/kWh)
  - Xinjiang: $111.5 MWh ($0.11/kWh or $11.15 c/kWh)
  - Jilin: $107.9 MWh ($0.11/kWh or $10.79 c/kWh)
  - Gansu: $132.3 MWh ($0.13/kWh or $13.23 c/kWh)

As the results show, there is a great variation in LCOE values for these provinces and the results range from $64.7 MWh in Yunnan to $132.3 MWh in Gansu. Moreover, the highest LCOE values are located in the provinces where there is the highest curtailment, namely Jilin (30% curtailment), Gansu (43%), and Xinjiang (38%). The lowest LCOE is located in Yunnan where there was only 4% curtailment in 2016. These results clearly show that, similar to solar PV, addressing the problem of curtailment would go a long way in improving the competitiveness of wind power in China.

As is the case with solar PV, it is not possible to compare one-to-one these LCOE results with those presented in Analysis 1 (Table 15, which shows data based on the different wind zones) or Analysis 2 (Tables 17 & 18, which also show results for each wind zone), as the underlying assumptions are different and also because the LCOE results are measured by specific province rather than the different wind zones.

Some observations are still possible, however. The LCOE of eight provinces assessed here fall in the range of $0.07/kWh - $0.09/kWh, which is similar to the LCOE results of Analysis 1 in Table 15 ($0.08/kWh - $0.10/kWh), but are higher that the results of Analysis 2 ($0.04/kWh - $0.06/kWh) and Analysis 3 ($0.05/kWh). Therefore, the current FiT system would also cover the LCOE results in this section.

However, the outliers in this section are Xinjiang ($0.11/kWh), Jilin ($0.11/kWh), and Gansu ($0.13/kWh) whose LCOE is higher than any of the three LCOE in the analyses presented here. Evidently, these are the provinces that show high curtailment. Based on this assessment, the existing FiT system could not cover the LCOE of these provinces.

Summary

From the analytical perspective, a major challenge to assessing the development of wind power and solar PV in China is the existence of different zones with different FiTs. Studies that only provide an average value (e.g. for the FiT or the LCOE) for the whole country do not do justice to the complexity of the matter. In this regard, Analyses 1 & 2 address wind power taking into consideration the different resource areas (Tables 15, 17, and 18) and Analysis 1 does the same for solar PV (Table 16). Analysis 4 fails in this regard, and only provides average data for wind power.

The author's own assessment has also relied on average values in order to provide an additional level of analysis to this assessment. Although a one-to-one comparison with the other analyses was not possible as the assumptions concerning, for example, investment costs, FLH, and operational lifetime are different, some common points were found in the case of wind power (e.g. the LCOE range). This was not the case of solar PV, however (i.e. major differences in LCOE).

8. Impact of the 2015 power market reforms

It is important to note that the recent energy policy changes in China are a complex matter and that reforms are still being implemented. Also, there will certainly be a number of unpredicted consequences that may need to be fixed in the future. Indeed, it is hardly predictable how all these policies will impact the Chinese electricity market as a whole. Taking Germany as an example, the legislatives packages that were prepared to promote the use of renewable energy in the country had unintended consequences, which required later amendments to legislation. The policy changes in China's electricity market will most likely be a constant work in progress that will address current challenges and most likely lead to new ones.

From the utility perspective, a good summary of the impact of policy changes is provided by Datang:

> *"Any change that creates adverse effect to the local wind conditions, local grid transmission capacity, on-grid tariffs, and changes in government policy in the "Three Northern" regions could reduce the electricity we generate and have an adverse impact on our power generation business."*[116]

Despite these unknowns, some observations about the impact of the recent policies can be made.

Grid expansion

The expansion of China's electricity grid could prove effective at alleviating the issue of curtailment. As this analysis has shown, curtailment is a serious issue for wind power and it is having a negative effect on the overall development of wind power as well as on utilities finances. Although, not discussed in major detail in this analysis, there are several plans for the expansion of the country's electricity grid[117].

Ensuring operational hours

In its most recent round of reforms, the government is pushing for the guaranteed purchase of solar and wind electricity, in particular in the provinces that have a high rate of curtailment. This would allow producers to continue to provide electricity and, therefore, reduce financial

[116] China Datang Corporation Renewable Power Co, Limited 2017: 23
[117] Energy Brain Blog 2017

losses. For example, as stated before in the case of solar power, rapid development and lack of grid infrastructure led to high levels of curtailment especially in Gansu, Xinjiang, and Ningxia[118]. Table 27[119] in the Appendix shows the number of guaranteed hours for solar power in two zones. For Zone I, these hours are set at 1,500 and for Zone II guaranteed hours range from 1,300 to 1,450. Both zones include projects in Gansu and Xinjiang where there is a high rate of curtailment.

As the results of the LCOE calculations show, high curtailment leads to high LCOE values. If the government manages to address the issue of wind and solar PV curtailment, the competitiveness of both sources will likely improve.

Reduction in FiT

Analyses 1-3 have used the previous FiT for wind power and solar power leading to a specific LCOE. Starting in December 2016, FiTs for both power sources are lower than before. This will have a negative impact on revenues per kWh sold and may increase the LCOE for both sources of power in China. However, if the issue of curtailment is addressed and operational hours are increased overall, these two factors could offset losses created by lower FiT.

Addressing Overcapacity

As explained in this study, China is suffering from a problem of power overcapacity. This is best demonstrated by Figures 5 and 6 that show that China has met power demand by operating power plants at low operational hours. Moving forward if China manages to make progress with the expansion of the grid, addresses the problem of curtailment, and adds more capacity by 2020 as planned, the problem of overcapacity will become more acute unless there is an increase in power demand. It is not really clear how China plans to manage the issue of overcapacity, but a positive sign is the plan to limit the deployment of coal plants as stated in the latest FYP for power development. Perhaps the FYP for 2021-2025 will include commitments to eventually reduce coal capacity in the country and allow cleaner electricity sources to increase their share in the country's power production mix.

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[118] DBS Asian Insights 2016: 28
[119] DBS Asian Insights 2016: 30

9. Conclusions

China is clearly moving away from an energy policy disregarding environmental concerns to a new policy where these concerns are high on the political agenda. This policy shift is contained in the country's FYPs and is also reflected in the plans to increase the level of renewable and nuclear power while capping the role of coal in the country's electricity mix.

In this regard, the development of wind power and solar PV has grown dramatically during the last ten years and while the latest FYP outlines further increased targets for the year 2020 it seems even these targets will be surpassed. As mentioned before, however, there are several challenges for the electricity sector that China will have to address over the next few years:

- Electricity overcapacity and plans to add more capacity by 2020 and beyond
- Curtailment of wind power and solar PV (and other power sources)
- The expansion of the electricity grid
- The impact of increasingly liberalising the energy market for all energy sources

The Chinese government is addressing these challenges with the latest round of policy reforms and there will likely be more policy reforms in the future.

China is clearly at an advantage when it comes to developing renewable energy, owing to its strong system of central planning. Without the direction and influence of the central government it is unlikely that China would have developed such massive levels of wind and solar PV capacities over the last ten years. On the other hand, central planning has led to deficiencies in the system (e.g. overcapacity and curtailment) and the government is trying to correct these.

However, China finds itself at a crossroad. As a matter of national policy, China is trying to bring several aspects of its economy closer to market forces and the energy sector in one important area in this regard. In view of the existing deficiencies in China's electricity sector, market forces may lead to less renewable energy development if investors do not have enough incentives to build additional capacity. The government could address such concerns by providing more financial incentives to investors, although this could lead to higher costs for renewable energy development and to subsidize a whole energy sector for a long period of time is not the best approach.

China has achieved an impressive economic development in the last decades. The electricity source of choice for most of this period has been coal. Reducing the role of coal in China's energy supply will not come fast and will not be easy. However, the policy direction has been decided and a combination of renewable energy, nuclear energy, and natural gas will see an increasing role in China in the years to come.

Finally, from an analytical perspective, further analyses concerning renewable energy in China should be undertaken examining the complexity of its electricity system, such as the different zones for wind and solar PV development and their particular FiT, FLH, and the electricity mix situation in the Chinese provinces, among other issues. Looking at the country as a single unit of analysis does not do justice to the different realities of the system and inaccurate conclusions could be reached concerning the future of the electricity system in China, including wind power and solar PV.

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Appendix

Table 21: Provincial Distribution of China's Wind Capacity (2016)

Province (autonomous region, municipality)	Installed capacity (MW)	Electricity production (GWh)	Curtailment (GWh)	Curtailment (%)	Productivity (full-load hours)
Beijing	190	300			1.750
Tianjin	290	600			2.075
Hebei	11.880	21.900	2.200	9%	2.077
Shanxi	7.710	13.500	1.400	9%	1.936
Shandong	8.390	14.700			1.869
Inner Mongolia	25.570	46.400	12.400	21%	1.830
Liaoning	6.950	12.900	1.900	13%	1.929
Jilin	5.050	6.700	2.900	30%	1.333
Heilongjiang	5.610	8.800	2.000	19%	1.666
Shanghai	710	1.400			2.162
Jiangsu	5.610	9.800			1.980
Zhejiang	1.190	2.300			2.161
Anhui	1.770	3.400			2.109
Fujian	2.140	5.000			2.503
Jiangxi	1.080	1.900			2.114
Henan	1.040	1.800			1.902
Hubei	2.010	3.500			2.063
Hunan	2.170	3.900			2.125
Chongqing	280	500			1.600
Sichuan	1.250	2.100			2.247
Shaanxi	2.490	2.800	200	7%	1.951
Gansu	12.770	13.600	10.400	43%	1.088
Qinghai	690	1.000			1.726
Ningxia	9.420	12.900	1.900	13%	1.553
Xinjiang	17.760	22.000	13.700	38%	1.290
Tibet	10				1.908
Guangdong	2.680	5.000			1.848
Guangxi	670	1.300			2.365
Hainan	310	600			1.781
Guizhou	3.620	5.500			1.806
Yunnan	7.370	14.800	600	4%	2.223
Total	148.680	240900	49600		**58.970**

Table 22: Provincial Distribution of China's PV Capacity

Province	Installed capacity (MW)	Of which: PV power plants	Newly installed capacity - 2016 (MW)	Of which: PV power plants
Beijing	240	50	80	30
Tianjin	600	480	470	440
Hebei	4.430	4.040	2.030	1.920
Shanxi	2.970	2.840	1.830	1.720
Inner Mongolia	6.370	6.370	1480	1.660
Liaoning	520	360	360	290
Jilin	560	510	490	450
Heilongjiang	170	120	150	110
Shanghai	350	20	140	0
Jiangsu	5.460	3.730	1.230	700
Zhejiang	3.380	1.310	1.750	880
Anhui	3.450	2.670	2.250	1.780
Fujian	270	110	120	80
Jiangxi	2.280	1.710	1.850	1.540
Shandong	4.550	3.360	3.220	2.470
Henan	2.840	2.480	2.440	2.340
Hubei	1.870	1.670	1.388	1.240
Hunan	300	0	10	0
Guangdong	1.560	680	920	610
Guangxi	180	90	60	40
Hainan	340	240	100	50
Chongqing	5	0	0	0
Sichuan	960	900	600	570
Guizhou	460	460	430	430
Yunnan	2.080	2.080	1.440	1.450
Tibet	330	330	160	160
Shaanxi	3.340	3.220	2.170	2.100
Gansu	6.860	6.800	760	740
Qinghai	6.820	6.820	1.190	1.180
Ningxia	5.260	5.050	2.170	1.990
Xinjiang	8.620	8.620	3.290	3.330
Total	**77425**	**67120**	**34578**	**30300**

Table 23: Current and Planned Capacity to Meet the 13th FYP Targets (Wind Power)

Province (autonomous region, municipality)	2016 Installed capacity (MW)	13Th FYP	Difference
Beijing	190	500	-310
Tianjin	290	1.000	-710
Hebei	11.880	18.000	-6120
Shanxi	7.710	9.000	-1290
Shandong	8.390	12.000	-3610
Inner Mongolia	25.570	27.000	-1430
Liaoning	6.950	8.000	-1050
Jilin	5.050	5.000	50
Heilongjiang	5.610	6.000	-390
Shanghai	710	500	210
Jiangsu	5.610	6.500	-890
Zhejiang	1.190	3.000	-1810
Anhui	1.770	3.500	-1730
Fujian	2.140	3.000	-860
Jiangxi	1.080	3.000	-1920
Henan	1.040	6.000	-4960
Hubei	2.010	5.000	-2990
Hunan	2.170	6.000	-3830
Chongqing	280	500	-220
Sichuan	1.250	5.000	-3750
Shaanxi	2.490	5.500	-3010
Gansu	12.770	14.000	-1230
Qinghai	690	2.000	-1310
Ningxia	9.420	9.000	420
Xinjiang	17.760	18.000	-240
Tibet	10	200	-190
Guangdong	2.680	6.000	-3320
Guangxi	670	3.500	-2830
Hainan	310	300	10
Guizhou	3.620	6.000	-2380
Yunnan	7.370	12.000	-4630
Total	148.680	205000	-56320

Table 24: Current and Planned Capacity to Meet the 13th FYP Targets (Solar PV)

Province	Installed capacity (MW)	13th FYP	Difference
Beijing	240		240
Tianjin	600		600
Hebei	4.430	12.000	-7570
Shanxi	2.970	12.000	-9030
Inner Mongolia	6.370	12.000	-5630
Liaoning	520		520
Jilin	560		560
Heilongjiang	170		170
Shanghai	350		350
Jiangsu	5.460	8.000	-2540
Zhejiang	3.380	8.000	-4620
Anhui	3.450	6.000	-2550
Fujian	270		270
Jiangxi	2.280		2280
Shandong	4.550	10.000	-5450
Henan	2.840		2840
Hubei	1.870		1870
Hunan	300		300
Guangdong	1.560	6.000	-4440
Guangxi	180		180
Hainan	340		340
Chongqing	5		5
Sichuan	960		960
Guizhou	460		460
Yunnan	2.080		2080
Tibet	330		330
Shaanxi	3.340	7.000	-3660
Gansu	6.860		6860
Qinghai	6.820	10.000	-3180
Ningxia	5.260	8.000	-2740
Xinjiang	8.620		8620
Total	77425	99000	-21575

Table 25: Wind Power Projects by Selected Utilities in 2016 (MW)

	China Longyuan Power Group	Huaneng Power Int.	Huaneng Renewables Energy Corporation	China Datang Corporation Renewable Power	Huadian Fuxin Energy Corporation Limited	*Province Total*
Heilonjiang	1.234	260		501	480,7	*2.476*
Jilin	547	272,5	396	648,1	196,5	*2.060*
Liaoning	1.003	145,5	1.402	373,8	144	*3.068*
Inner Mongolia	2.635	99	2.467	2.754	2.077	*10.032*
Hebei	1.170	49,5	361,5	99	148,5	*1.829*
Gansu	1.289	1.141,50		845,8	1.739	*5.015*
Shandong	393	100,12	1.002	860,5	48	*2.404*
Jiangsu	1.248	284,1			100	*1.632*
Hunan	48	234			86	*368*
Hubei		120		48		*168*
Jiangxi		48				*48*
Anhui	733,1	50		48	96	*927*
Yunnan	769,5	136	1.116	296,25	223,5	*2.541*
Hainan	99	47,2				*146*
Guizhou		24				*24*
Shaanxi			358,5	149		*508*
Xinjiang	1.541		447,5		594	*2.583*
Shanghai	47,5		108	204,2		*360*
Sichuan			493			*493*
Guangdong	75,74		502	49,5	99	*726*
Guangxi	95,5		49,5	148		*293*
Shanxi	829,5		743,5	576	196,5	*2.346*
Zhejiang	227,9		74,5		34	*336*
Guizhou	641,5		729	48		*1.419*
Fujian	665,1			48	78	*791*
Tianjin	132					*132*
Ningxia	724,7			497,5		*1.222*
Tibet	7,5					*8*
Chongqing	149,5			50		*200*
Jangxi	40					*40*
Henan				100,75	48	*149*
Utility Total	***16346***	***3011,42***	***10250***	***8345,4***	***6388,5***	**44.342**

Table 26: HPI's Wind Power Average Tariff (RMB/MWh) in 2016 (VAT inclusive)

Province	Wind Project	2012	2013	2014	2015	2016	2017
Heilongjiang							
	Sanjiangkou						630
	Linjiang Jiangsheng						630
	Daqing Heping Aobao						630
Jilin							
	Zhenlai						595
	Siping						610
	Tongyu Tuanjie						580
Liaoning							
	Wafangdian	610,82	632,85	609,68	598,12	603,72	620
	Changtu	610	605,3	602,82	590,93	626,09	620
Inner Mongolia							
	Huade	520	520	520	520	471,22	520
Hebei							
	Kangbao	536,72	534,47	538,84	538,14	554,6	540
Gansu							
	Jiuquan	520,6	520,6	520,6	473,12	367,54	520,6
	Jiuquan II			540	497,75	402,36	540
	Yumen			520,6	472,01	390,06	520,6
	Yigang					447,65	580
Shandong							
	Muping						640
	Penglai						635
	Rushan						640
	Changdao						630
	Rongcheng						630
	Dongying						640
Henan							
	Zhumadian						610
Jiangsu							
	Qidong	542,65	541,34	555,92	556,76	533,91	549,67
	Rudong		610	610	610	606,24	610
	Tongshan					610	610
Hunan							
	Subaoding			494	611,72	610	610
	Guidong				610	610	610
Hubei							
	Jieshan				610	610	690
Jiangxi							
	Jianggongling					610	610

Yunnan							
	Fuyuan			610	600,61	494,71	610
Guizhou							
	Panxian					610	610
Hainan							
	Wenchang			619,72	571,95	609,78	610

Table 27: Guaranteed Utilization Hours for Solar Power

Areas	Regions	Guaranteed Utilization Hours
Zone I	Ningxia	1.500
	Qinghai Haixi	1.500
	Gansu : Jiayuguan, Wuwei, Zhangye, Jiuquan, Dunhuang, and Jinchang	1.500
	Xinjiang : Hami, Tacheng, Altay, and Karamay	1.500
	Inner Mongolia (except Chifeng, Tongliao, Xing'an League, and Hulunbeier)	1.500
Zone II	Qinghai (excluding Zone-I areas)	1.450
	Gansu (excluding Zone-I areas)	1.400
	Xinjiang (excluding Zone-I areas)	1.350
	Inner Mongolia : Chifeng, Tongliao, Xing'an League, and Hulunbeier	1.400
	Heilongjiang	1.300
	Jilin	1.300
	Liaoning	1.300
	Hebei : Chengde, Zhangjiakou, Tangshan, and Qinhuangdao	1.400
	Shanxi : Datong, Shuozhou, and Xinzhou	1.400
	Shaanxi : Yulin, Yan'an	1.300

Table 28: LCOE for Solar PV (Zone I)

Full Load Hours	1.500	hours/year
Investment costs	970,00	$/kWe
Cost of capital	7%	%/year
O&M (incl. all variable costs) - 1% of Investment costs	9,70	$/kWe
Investment Time	25	Years

Table 29: LCOE for Solar PV (Zone II)

Full Load Hours	1.450	hours/year
Investment costs	970,00	$/kWe
Cost of capital	7%	%/year
O&M (incl. all variable costs) - 1% of Investment costs	9,70	$/kWe
Investment Time	25	Years

Table 30: LCOE for Wind Power (Data input)

Full Load Hours	Table 31	hours/year
Investment Costs (1)	1.243,00	$/kWe
Cost of capital (1)	7%	%/year
O&M (incl. all variable costs) - 3% of Investment costs	37,29	$/kWe
Investment Time (1)	25	years

Table 31: LCOE Results for Wind Projects

Provinces	Curtailment (%)	FLH	LCOE ($/MWh)
Hebei	9%	2.077	69,3
Shanxi	9%	1.936	74,3
Inner Mongolia	21%	1.830	78,6
Liaoning	13%	1.929	74,6
Jilin	30%	1.333	107,9
Heilongjiang	19%	1.666	84,4
Shaanxi	7%	1.951	73,7
Gansu	43%	1.088	132,3
Ningxia	13%	1.553	92,6
Xinjiang	38%	1.290	111,5
Yunnan	4%	2.223	64,7