



Development of wind power industry in China: A comprehensive assessment

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ABSTRACT

In recent years, China's wind power industry has developed rapidly, and become the global wind power leader. At the same time, China's wind power industry is also facing many problems and challenges. In this paper, a comprehensive assessment is presented to reveal the development history of China's wind power industry, power demand and cost, regional distribution of wind power, wind turbine manufacturers, and government incentives to wind power industry. Subsequently, future development and challenges are proposed, focusing on the challenge of wind power integration and consumption, the challenge of management and market competition mechanism, and the challenge of large-scale and rapid development. Finally, the corresponding measures are put forward. The fundamental goal of this paper is to understand the history, current situation and future challenges of China's wind power industry.

1. Introduction

Fossil energy consumption causes the pollution of the environment [1] and is dwindling. Thus, it is necessary to develop alternative energy sources [2]. Speeding up the development of renewable electricity generation has become a common understanding of many countries to promote the transformation and development of energy and cope with global climate change [3]. Wind power is one of the most promising renewable energy technologies in the future [4]. It has many advantages, such as rich resources, strong economic competitiveness, and climate change mitigation [5]. In some countries, such as Denmark, Spain, and Germany, wind power has become an important part of the new power supply. In China, economic development remains a major strategic task. Energy consumption will maintain a certain growth rate in the future for a fairly long period. However, the energy structure is too simple presently to support the sustainable economic development since coal is the major energy resource [6]. If coal is still used as that previously, China will suffer as the result of environmental pollution [7]. An investigation shows that wind power and hydroelectricity are the two low-carbon energy sources which have the most potential to increase China's energy security [8].

China also faces challenges in promoting wind power generation [9]. The mismatch between the upstream chain and the downstream chain is the main factor in restricting wind power industrialization [10]. Besides, there are some other factors that influence the development of China's wind power industry such as resource potential, GDP growth, technological progress, and emission regulation scheme. Also,

the rapid growth of China's wind power industry is closely related to the wind power policies issued by the Chinese government [11]. At different stages of development, wind power policy is also evolving [12]. From 1995, more than twenty organizations have independently or jointly issued development policies, some of them have played a very important role. For example, since the promulgation of the Renewable Energy Law (2005), the wind power industry has enjoyed a favorable development environment in China [12]. Surveys show that price policy plays a greater role than non-price policy in promoting wind power development [13]. At the same time, the rapid increase of installed capacity has also promoted the manufacturing industry of wind turbines to increase rapidly in China; from 2003, the localization rate and the unit capacity have been growing rapidly [14].

Wind power in China has great potential [15]. In recent years, China's wind power industry has made remarkable achievements [9]. China has become the world's wind power leader, has the largest installed capacity of wind farms [16]. Also, there have been some reviews on China's wind power industry. For instance, the evolution of wind energy policies in China (1995–2014) was analyzed based on policy instruments in [11], but new changes have taken place in wind power policy today; current situation and prospect of renewable energy in China were investigated in [17], and this investigation focused on the energy structure; comparison of policies and present situation of the development of renewable energy in Australia and China was carried out in [18], including management mechanisms, governance structures and status of renewable energy development; a short review on the development and policy of wind energy in China has introduced the

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wind energy resources, wind energy shares, and wind energy policy in [19]; driving factors for wind curtailment under economic new normal in China was also investigated in [20]. However, most of the reviews are carried out from a specific angle. In addition, due to the rapid development of wind power industry, many new features have emerged. Thus, a comprehensive assessment will help to understand the history, current situation and future challenges of China's wind power industry by combining some recent statistics. The remaining part is organized as follows. In Section 2, the development history of modern wind power in China will be introduced. In Section 3, regional distribution of wind power in China is investigated, including wind resource distribution and wind power capacity construction. The basic characteristics of wind turbine manufacturers are introduced, and some problems faced by manufacturers are also raised out in Section 4. A number of influential government incentives are introduced in Section 5, the future development and challenges are summed up in Section 6. Finally, Section 7 ends the paper by summarizing the main achievements.

2. Development history and energy demand

2.1. Development history

The development history of modern wind power in China can be roughly divided into four stages as shown in Fig. 1, namely early demonstration stage, industrialization exploration stage, industrialization development stage, and steady development stage [21]. The four stages are divided according to the corresponding landmark event, which is somewhat different from that in [21]. In 1986, China's first wind farm – Malan wind farm in Rongcheng, Shandong Province, is a milestone in the history of China's wind power, from which China's wind power is really in its development stage. However, in the early demonstration stage, the scale of China's wind power is very small. For example, in Malan wind farm, only four wind turbines operated (each 11 kW). The main goal is to carry out a number of wind farm projects and promote wind turbine development with the help of the European wind power technologies and funds. In this stage, the wind power capacity is about 26,000 kW. In 1995, China promulgated the outline of new energy and renewable energy development, which can be seen as a turning point for China's wind power industry. From 1995 to 2006, wind power began to keep a relatively rapid development so-called industrialization exploration stage. Especially after 2003, development speed has been significantly improved. According to statistical data by Chinese wind energy association (CWEA), the wind power capacity in 2003 is

546 MW, but in 2006 it has reached 2537 MW. From 2006 to 2010, China's wind power industry entered the period of industrialization development stage. After enacting renewable energy law in 2006, China's installed capacity of wind power has been increasing rapidly. By the year 2010, China became the global wind power leader, that is, China entered the steady development stage.

2.2. Power demand and cost

In the next twenty years, the process of industrialization and urbanization in China will advance rapidly. Resultantly, the economy will continue to grow at a certain rate. According to the relationship between energy and economic development, many research institutions, such as International Energy Agency, Institute of Energy economics (Japan) and National Energy Research Institute (China), have carried out the research of China energy demand forecasting [22]. In Fig. 2, both the primary energy demand and total power demand are given for 2030 based on different scenarios and from different institutes. Under different scenarios, the future demands of Chinese energy and power forecasting are different. For example, International Energy Agency considers three different scenarios, with 2011 as the base period. The three scenarios are based on assumptions about economic and population growth, energy and climate policies, technology deployment. The conclusions are that the primary energy demand can reach 62 million tons of standard coal and the power demand is 10.4 billion MWh based on the current policy scenario; the primary energy demand is 56.3 million tons of standard coal and the power demand is 9.2 billion MWh based on new policy scenario; the primary energy demand is 47 million tons of standard coal and the power demand is 7.8 billion MWh based on 450 scenario. Today, China is the largest consumer of primary energy by a wide margin in the world [8]. Also, the Chinese government has promised that, by 2030, non-fossil energy will account for about 20% of the primary energy consumption. Thus, for China's wind power industry, there is still a long way to go.

With the passage of time, the scale of the wind power industry is gradually expanding, and the cost of wind power generation is decreasing. In general, the cost of wind power generation can be described by using the cost per kilowatt hour (kWh). It mainly includes investment cost, operation, maintenance cost and financial cost. According to the white paper: “cost per kilowatt hour of wind power in China, 2025” issued by General Electric Co. in 2016, the cost fluctuation range is roughly 0.471 yuan (\$ 0.0736) per kilowatt hour to 0.668 yuan (\$ 0.1044) per kilowatt hour in flat terrain region, 0.531 yuan (\$ 0.0829) per kilowatt hour to 0.755 yuan (\$ 0.1179) per kilowatt hour in the complex terrain region. At this stage, the cost per kilowatt-hour of wind power is still higher than that of coal-fired power generation, but close to that of gas power generation. As stated in the white paper “cost per kilowatt hour of wind power in China, 2025”, further efforts should be made to reduce the cost of wind power, including: optimization of wind resource evaluation and site selection, optimization of wind turbine type selection, technological progress and breakthrough, optimization of power grid dispatching, digital industry, and so on.

3. Regional distribution of wind power

3.1. Wind resource distribution

China's wind resources have the characteristics of seasonal variation. China is located in the southeastern part of the Eurasian continent. Due to the different physical properties of land and sea, the Asian continent is the source of cold air which will spread around in winter. Land in summer is quickly heated, forming a heat low pressure and causing warm air from the surrounding ocean blowing into the low-pressure center. This leads to the contrary prevailing wind in winter and summer. Daily and seasonal variations indicate that spring and

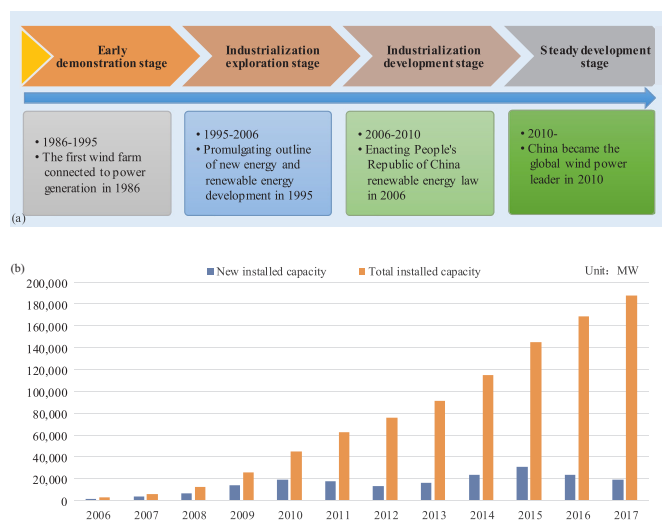


Fig. 1. Development history of wind power in China (data from CWEA and WWEA). (a) Four stages of wind power development in China; (b) installed capacity from 2006 to 2017.

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