Electrical Power and Energy Systems 69 (2015) 58–66

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Evaluating the performance of wind farms in China: An empirical review

Shih-Fang Lo [a,*], Chou-Yen Wu [b]

[a] Center for Green Economy, Chung Hua Institution for Economic Research, Rm. 531, 75 Chang-Hsing St., Taipei 106, Taiwan
[b] Department of Finance, National Chengchi University, No. 64, Sec. 2, ZhiNan Rd., Wenshan District, Taipei 116, Taiwan

ARTICLE INFO

Article history:
Received 30 April 2014
Received in revised form 20 August 2014
Accepted 7 December 2014
Available online 21 January 2015

Keywords:
Renewable energy law
Grid
Capacity factor

ABSTRACT

China is now the world leader in wind power with total installed capacity and its strong policy support. In this paper, we take the 610 wind farms located in China as an example and explore the relationships between a wind farm's operational performance and several key factors, i.e., resource area, regional location, and scale. Our empirical results imply that policy and approval of wind farms may affect performance of wind farms, leading to large difference on performance of wind farms in different provinces of China.

Introduction

Wind offers an important alternative to fossil fuels as a source of energy for electricity generation, and has the potential to reduce CO_2 emissions significantly. For example, the global installed capacity of wind power has increased dramatically since 2007, from 94 GW in 2007 to 282.5 GW in 2012 [9–11,4]. In the end of 2010, China with 44.7 GW of installed capacity surpassed the United States to be ranked number one in the world [9,10]. Despite the overall investment declines in China, in the end of 2013, China consolidated its position as global market leader, with a cumulative capacity of 91.4 GW according to the GWEC statistics and REN21 [12].

China has favorable natural conditions for generating wind energy; however, the distribution of wind resources is not quite even. According to the latest survey data from China Meteorological Administration (CMA), the technical potential for wind energy generation is around 1000 GW per year. Besides, the natural conditions are most favorable in northern China, such as in the provinces of Inner Mongolia, Jilin and Xinjiang, and several eastern coastal regions, whereas the potential in south-central China is limited. Fig. 1 shows the numbers of wind farms across regions in China in 2010. In terms of total installed capacity in China, 23.27% of these farms are installed in Inner Mongolia, followed by Liaoning (14.68%), Hebei (9.42%), Heilongjiang (8.59%) and Jilin (8.59%) provinces. It is obvious that the distribution of wind farms is highly correlated with the natural condition of wind resources.

The development of renewable energy in China was rapidly boosted after the Renewable Energy Law was adopted in 2005. In addition, China continued to benefit from a $30 billion "green" stimulus package, which had been announced as a response to the financial crisis [17]. Lam et al. [5] find that an immediate impacts on cash flows of a wind energy developer is the directly drivers of wind investments in China, such as government financial assistance, easy and inexpensive transmission access, wind energy cost decline, and a high feed-in-tariff. According to the statistics of the China Wind Energy Association, the growth of investment in new capacity doubled year by year after 2006 and the total installed wind turbine capacity amounts to 53,764 MW in 2012. The Law is subsidy-based, but the significant increase in installed wind power capacity was not completely expected. For example, total installed wind power capacity reached approximately 45 GW in 2010, which exceeded the former national target (5 GW by 2010 and 30 GW by 2020) issued by the National Development and Reform Commission (NDRC) in the 'Medium to Long-term Renewable Energy Development Plan' in 2007. The new targets for on-grid wind power of 100 GW by 2015 and 200 GW by 2020 were therefore revised in the 12th Five-Year Plan (2011–2015).

The governmental political and regulatory support as well as lower labor and manufacturing costs have not only driven strong growth, but have also strengthened the related businesses in China. The market share of Chinese turbine manufacturers amounts to 70% domestically [1]. Furthermore, Chinese enterprises accounted for 4 of the world's top 10 wind turbine manufacturers, namely, Sinovel, Goldwind, Dongfang, and United Power. The major developers of wind projects in China remained predominantly state-owned enterprises, namely, Longyuan, Datang, Huaneng, Huadian, CPI, and Guohua [9].

* Corresponding author. Tel.: +886 2 2735 6006x531; fax: +886 2 2739 0610.
E-mail addresses: shihfang.lo@gmail.com (S.-F. Lo), chouyen0312@gmail.com (C.-Y. Wu).

http://dx.doi.org/10.1016/j.ijepes.2014.12.034
0142-0615/

Behind the magnificent growth, the development of wind power in China is facing a number of challenges. Liu [8] finds that around 30% of the installed capacity of wind power is left to lie idle, which is generally regarded as the overinvestment problem. Firstly, the achievements of local and central government officials are only measured by the installed capacity rather than by energy production as they were previously. Wind power deployment is largely controlled by the local governments practically [18]. Local governments have the power to authorize wind projects smaller than 50 MW after they put the projects on record with the NDRC. Wind projects larger than 50 MW are authorized and managed by the NDRC. Since local governments can approve projects more easily and more quickly than the NDRC, some wind farm operators separate their projects into several stages, each of which is smaller than 50 MW. This has led to many wind farms with 49.5 MW of installed capacity in China. The sample used in this study, for instance, of around 25% wind farms (or 62 of 249 wind farms) and 30% wind farms (or 108 of 361 wind farms) had an installed capacity of 49.5 MW at the end of 2009 and 2010, respectively. Moreover, wind projects authorized by local governments may not be included in the national plan for grid-access, which is one of the reasons why the grid and wind farms do not develop in harmony. Therefore, China's National Energy Bureau (NEB) has drafted new regulations to standardize the examination and approval of wind projects smaller than 50 MW (China Daily Report, 2011). According to the draft, local governments must receive the approval of the NEB before they approve wind projects smaller than 50 MW. This is in order to facilitate the monitoring of the development progress. For instance, Fig. 4 shows that the growth of newly increased capacity in 2011 and 2012 experienced a decline comparing to the period between 2006 and 2010.

Secondly, although China has favorable natural conditions for generating wind energy, the wind farms have developed out of harmony with the electricity grid construction, which has resulted in a large proportion of the electricity generated by wind turbines being wasted. The challenge to the grid-connected mainly influences wind power infrastructures development in China [2]. Actually, power grid construction is significantly behind the construction of wind farms. For example, the rate of grid-connected for wind power was only 62% in 2009. It was improved since the grid-connected for wind power was required by the *Amendments to Renewable Energy Law of the People's Republic of China* implemented in 2010. In 2011, the rate of grid-connected for wind power increased to 73.4%. Table 1 shows the source of power generation in China from 2009 to 2011. It indicates that although 3.23% of installed capacity in China is contributed by grid-connected wind power, only 1.18% of electricity generation is provided by grid-connected wind power in 2009. This trend seems to be persistent in 2011, 4.35% of installed capacity is contributed by grid-connected wind power and still only 1.57% of electricity generation is provided by grid-connected wind power. Actually, it is estimated that approximately 30% of wind turbines are not connected to the electricity grid [16]. Furthermore, the main area of electric consumption is concentrated in southeast coastal area in China but high-density wind resource areas and development of wind power are concentrated in the "Three Northern Area" [2]. The electric load centers are usually far from the high-density wind resources, bringing the difficulties in grid connection. Transformer losses may be directly affected by long distance, leading to large waste on power transmitted long distances. For example, Shi [14] proposes that the low level of efficiency of the wind farms in China is possibly caused by site selection. Li et al. [7] also suggest that both the capability of grid infrastructure and the availability of backup systems for wind farms in China must be tackled. Li et al. [6] suggest that the risks from power grid construction lag, deficient policy, and operation mechanism have negative impacts on wind energy development in China. This has been directly restricting development and construction of wind farms [2,7,8,3,6].

Thirdly, many wind farms are running at a low level of efficiency owing to domestically made wind turbines that lack reliability [2,7]. During the period from 2006 to 2010, market share of domestically made wind turbines grew dramatically since 70% of the components of wind turbine should be domestically manufactured required by "Renewable Energy Law of the People's Republic of China." Some Chinese wind turbine manufacturers developed rapidly from the prototype stage to mass production, resulting in low electricity production [14]. Low quality of domestically made wind turbines leaded to wind power incidents in China, promoting the government changed the previous policy which are only measured by the installed capacity rather than by energy production. *Amendments to Renewable Energy Law of the People's Republic of China* implemented in 2010 puts emphasis on both actual electricity generation and regulation. New investment projects of wind farm were also strictly approved. Besides, the relatively high generation costs and low on-grid prices of wind electricity have a direct impact on wind development in China. Those points are potential threats to the wind industry in the long run.

Our sample obtained from China Electric Power Yearbook consists of 610 wind farms located in China in 2009 and 2010. We investigate the relationship between a wind farm's operational performance and its resource area, regional location and scale by using the N-way ANOVA method. In general, the amount of energy generated by wind farm is affected by many factors; however, only several factors, such as wind resource, region, and scale of wind farm, are considered in this paper since *China Electric Power Yearbook* only provided name of wind farm, location (province) of wind farm, installed capacity, electrical generation, and annual equipment utilization hours. Finally, the data of wind farms in China is obtained from *China Electric Power Yearbook* (2011 *and* 2012), but the data is only comprised as 2009 and 2010.

Then, the location of wind farms is sorted by five-level wind resource areas defined by the National Development and Reform Commission (NDRC). It is generally assumed that wind farms located in high-density wind resource areas are expected to outperform those located in low-density areas. Large-scaled wind farms should be associated with better operational performance compared with middle-scaled and small-scaled ones. The study therefore aims to explore whether the assumptions still hold in China.

This paper is organized as follows: Following this introduction, the next section provides an overview of wind power development in China. Section 'Data and methodology' introduces the estimation methodology, the data used, and the analytical process. Section 'Empirical results' presents the empirical results. Section 'Conclusions' concludes this paper.

Data and methodology

Data

This study examines whether wind farms perform differently across China, as well as the underlying reasons. From the *China Electric Power Yearbook* 2010 *and* 2011 (published in 2011 and 2012, respectively), we establish a data set for 22 regions in China where at least one wind farm was located (19 provinces and 3 municipalities) in 2009 and 2010. Since a longitudinal data set across years is not available before the year 2009 and after 2010, this study places emphasis on cross comparisons within one period. In general, the amount of energy generated by wind farm is affected by many factors; however, only several factors, such as wind resource, region, and scale of wind farm, are considered in this paper since *China Electric Power Yearbook* only provided name