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Energy performance of wind power in China: A comparison among inland, coastal and offshore wind farms

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ABSTRACT

China has the largest wind power installation across the world due to the tremendous inland wind capacity and the government has begun to pay much more attention to develop offshore wind power in recent years. During the shift from inland to offshore, it is very important to identify the difference of energy performance between them. This paper establishes 4 indicators; energy consumption intensity (EI), energy payback time (EPT), energy payback ratio (EPR) and energy return intensity (ERI) to measure the energy performance of wind farms. Meanwhile, coastal wind farms are introduced as a smooth transition cases from inland to offshore wind farms. Each of the 8 farms for inland, coastal and offshore wind are taken as the examples to assess. The results show that inland and coastal wind farms have the similar energy performance, which pose significant difference with that of offshore wind farms. Based on the relatively lower EI, EPT and higher EPR, land-based inland and coastal wind farms are better for energy efficiency. From the energy performance route of wind farms, the energy performance strength of offshore wind farms only appear after 9.2 years of operation when compared to the land-based wind farms. Therefore, it is wise to set a long-term moderate target for offshore wind power development in China, just as the highest ERI of offshore wind farms can only be obtained in a long-term period.

1. Introduction

China's energy supply has been heavily relied on coal, and this situation will not change for energy security in the near future (Wang and Tian, 2015). However, China has strived to develop renewable energy which includes hydro, wind, nuclear, solar, biomass and oceanic power to alleviate greenhouse gas (GHG) emissions and environmental pollution caused by coal consumption (Chen et al., 2016; Guo et al., 2016). With respect to technical and economic advantages, wind power is the second largest renewable energy source after hydropower in China (Shen and Luo, 2015). Installed wind power capacity has accumulated to 145 GW by 2015 in China, which is the largest installation across the globe.[1] Considering series of favorable policies for renewable energy will be implemented in the "13th five period", the wind power in China is still promising (Chen, 2011; Zhao and Ren, 2015).

Though China dominates the world's wind power capacity, this domination has been merely focused on inland wind power. When it comes to offshore wind power, China had only completed about 20% of its proposed 5000 MW capacity by 2015.[2] An uneven distribution of wind capacity has been mainly distributed in northwestern and northeastern inland China, which is far from the electricity consumption center, or the coastal region (Han et al., 2009; Liu and Kokko, 2010). Therefore, this uneven distribution un-facilitates the wind electricity transmission and consumption, with the addition of competition among the whole electricity sector (Weigelt and Shittu, 2016), the full load hours of these inland wind farms has been decreased in recent years, which becomes even less than 1200 h per year.[3] That is to say, it is urgent for China to divert from the over-development of inland wind power to the immature coastal and offshore wind power.

There are many technical differences between land-based wind power and offshore wind power during the course of their lifetimes

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[2] The offshore wind power development data cited from the news report of China Energy Website http://www.china5e.com/index.php?m=content&c=index&a=show&catid=13&id=926250.

[3] The operation hours data of inland wind farms cited from the news report of China Energy Website http://www.china5e.com/news/news-945353-1.html.

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including construction, operation and maintenance (Koh and Ng, 2016; Ortegon et al., 2013). Construction and maintenance course are related to energy input, and operation course is related to energy output. Therefore, technical differences will induce the energy performance difference. Energy performance once used to show the energy saving and energy consumption of buildings, and then be introduced to energy industry to show its energy production potential (Crawley et al., 2008; Bakar et al., 2015). Energy performance investigation is of great importance for the China national energy saving and emission reduction strategy. Energy performance is related to how much energy is consumed and produced, and when can energy return back, both of them are often the main indicators to measure the feasibility of the whole energy industry (Raadal et al., 2014; Zhu et al., 2015). Though energy performance has been investigated for wind power, it puts emphasize on the energy consumption and energy return of inland wind farms in China (Xue et al., 2015). More details and variations about energy performance need to be applied to different types of wind farms, especially in the context of rapid development of offshore wind farms. Therefore, in order to smooth the transition from inland wind power to offshore wind power, this paper introduces and analyses coastal wind power, of which is a land-based construction but has an ocean-based wind power source. A comprehensive comparison of energy performance among different types of wind farms can help the redistribution and sustainable development of wind power in China.

2. Methodology

Energy performance describes the comprehensive issues related to energy input, energy output and the processes between them (Droutsa et al., 2016; Gangolells et al., 2016). Wind farms consume energy (input) during their construction and generate energy (output) during operation.

2.1. Energy performance indicators

With regard to energy performance, 4 indicators have been established as follows: energy consumption intensity (EI), energy payback time (EPT), energy payback ratio (EPR) and energy return intensity (ERI).

(1) Energy consumption intensity (EI) expresses the amount of energy consumption per installed unit capacity, TJ/MW. The energy consumption in this paper is focused on the energy investment during wind farm construction, which includes the energy investment of infrastructure and extraction/transport processes. EI is of most importance to measure the energy cost, and a low EI contributes to high energy efficiency.

(2) Energy payback time (EPT) expresses the amount of time taken to offset the energy consumption during construction. Wind farms generate internal energy (electricity) during their operation period to pay back the external energy invested during construction. EPT shows when the energy input and energy output can be balanced, and a low EPT contributes to high energy efficiency.

(3) Energy payback ratio (EPR) expresses the amount of energy output per unit energy input across the whole lifetime. EPR shows that energy output is based on the energy input. The higher the EPR is, the lower the EPT is. A high EPR contributes to high energy efficiency.

(4) Energy return intensity (ERI) expresses the net energy output per installed unit capacity across the whole lifetime. The net energy output is the accumulated electricity production after the offset of the energy investment. ERI is the key indicator that shows the energy performance of wind farms in the long run, which represents the final energy production capacity no matter the producing speed. A high ERI contributes to high energy efficiency.

These 4 energy performance indicators can be calculated as follows:

$$EI = E_n / C \tag{1}$$

$$EPT = E_n / P \tag{2}$$

$$EPR = P \cdot L / E_n \tag{3}$$

$$ERI = (P \cdot L - E_n) / C \tag{4}$$

where, E_n is the energy consumption during wind farm construction, TJ; C is the installed capacity of the wind farm, MW; P is the annual power generation of wind farm, TJ; L is the lifetime of the wind farm, we take the commonly cited amount of 20 years as the lifetime of wind farm (Arvesen and Hertwich, 2012; Wagner et al., 2011).

2.2. Energy consumption assessment

The calculation of energy performance indicators must be based on the energy consumption assessment. Energy consumption during the wind farm construction period may not be recorded accurately for complicated reasons. The Economic Input-Output Life Cycle Assessment (EIO-LCA) model is used to calculate the energy consumption during the wind farm construction. The EIO-LCA model is developed by Carnegie Mellon University and a module based on a Chinese input-output table is established for the assessment of China, which has been applied to assess the energy and GHG issues for energy sectors in many countries (Egilmez and Park, 2015; Zhang and Xu, 2015). For wind farm assessment in this paper, the model input is the producer price and the model output is energy consumption. The producer price includes civil work price and equipment price, which has two different sector choices in the EIO-LCA model (Table 1). Additionally, for more authentic results, we adjust the initial input and output of the model based on price index and energy intensity according to the following methods:

$$PP_m = PP_n \times \frac{PPI_m}{PPI_n} \tag{5}$$

$$E_n = E_m \times \frac{I_n}{I_m} \tag{6}$$

where, PP is the produce price of a wind farm; PPI is the produce price index; E is the energy consumption of wind farm construction; I is the energy intensity; the subscript m and n represent the corresponding value in the EIO-LCA model setting year and wind farm construction starting year, respectively.

3. Case study

In this section we will take 24 wind farms (8 inland farms, 8 coastal farms and 8 offshore farms) as cases to calculate and compare energy performance, using the methodology mentioned above. All of these wind farms are constructed or are being constructed.

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