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Optimal integration of offshore wind power for a steadier, environmentally friendlier, supply of electricity in China ☆

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HIGHLIGHTS

- Evaluating the potential for offshore wind power in near-shore areas of China.
- Optimizing contributions from offshore wind power distributed over three important coastal zones.
- Analyzing variability characteristics of hourly power outputs from 12 offshore sites in China.
- Evaluating the firm capacity that could be realized by an interconnected offshore wind system.

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ABSTRACT

Demand for electricity in China is concentrated to a significant extent in its coastal provinces. Opportunities for production of electricity by on-shore wind facilities are greatest, however, in the north and west of the country. Using high resolution wind data derived from the GEOS-5 assimilation, this study shows that investments in off-shore wind facilities in these spatially separated regions (Bohai-Bay or BHB, Yangtze-River Delta or YRD, Pearl-River Delta or PRD) could make an important contribution to overall regional demand for electricity in coastal China. An optimization analysis indicates that hour-to-hour variability of outputs from a combined system can be minimized by investing 24% of the power capacity in BHB, 30% in YRD and 47% in PRD. The analysis suggests that about 28% of the overall off-shore wind potential could be deployed as base load power replacing coal-fired system with benefits not only in terms of reductions in CO_2 emissions but also in terms of improvements in regional air quality. The interconnection of off-shore wind resources contemplated here could be facilitated by China's 12th-five-year plan to strengthen inter-connections between regional electric-power grids.

1. Introduction

Production of electricity from wind power has expanded rapidly in China since 2006, with an annual growth rate of over 90% from 2006 to 2011. Total installed national capacity amounted to 62.7 giga-watts (GW) at the end of 2011. About 73.2 TWh of electricity was generated form wind in China in 2011, accounting for 1.6% of total electricity generation in the country (Fig. 1) (SERC, 2012). Although almost all of the increase of wind power has come from development of land-based wind farms, offshore wind power in China has received increasing attention and is expected to expand significantly in the future. The first offshore wind project, consisting of 34 3-MW wind turbines (102 MW), was implemented at Shanghai Donghai Bridge in 2010. In the same year, four more offshore projects, including Binhai (300 MW), Sheyang (300 MW), Dafeng (200 MW) and Donghai (200 MW) successfully completed the first concession bidding process for offshore demonstration projects (Li et al., 2011). The successful bidding prices for these projects ranged from 0.62 RMB/kWh to 0.74 RMB/kWh, about 9.1 cents/kWh to 10.9 cents/kWh in 2010 US dollars.

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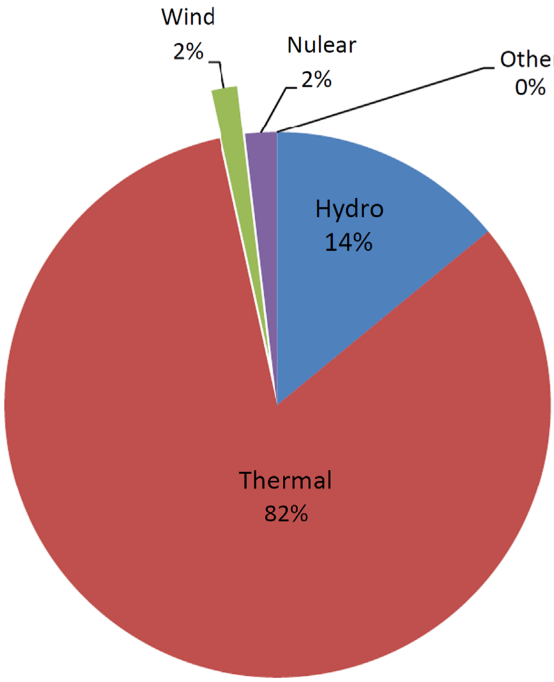

Fig. 1. The electricity generation mix of China in 2011. Data derived from Chinese State Electricity Regulatory Commission.

To ensure profitability, these projects benefit from a favorable concession policy, which guarantees higher bus-bar prices for electricity produced from offshore wind farms as compared with production from either onshore facilities or from conventional coal-fired power plants.

China's coal reserves and production are concentrated to the North and West of the country (particularly in Shanxi, Shaanxi and Inner Mongolia). To meet the increasing demand for energy in southeastern coastal provinces, where over 40% of the population is located (NBS, 2012), coal is first transported by rail east to the coast and shipped subsequently to the high demand centers in southeast. In 2010, 92% of coal consumed in Jiangsu province (responsible for the second highest GDP of all provinces in China) was imported from inland provinces. Rich onshore wind power resources tend also to be located to the North and West of China. To harvest this renewable source requires significant expansion of existing transmission grid system on a national scale. We shall argue here that investment in offshore wind resources would significantly reduce the demand for coal supply for the south, while providing at the same time a valuable low-carbon source of electric power.

The intrinsic variability of the output of power from individual wind farms poses a problem for integration at scale of this source into the existing power system. Production of electricity in coastal provinces of China is currently dominated by sources fueled by coal, with percentages ranging from 55% in Guangxi to as high as 91% in Shandong in 2010 (Ma et al., 2011). Coal-fired systems are relatively inflexible, with limited ramp-up and ramp-down capability to cope with the additional variations introduced by wind power. Direct or indirect electricity storage could help address this potential incompatibility. A number of pumped hydro power stations have already been built in China to cope with the increasing diurnal variability of load. Opportunities for further expansion of pumped storage are limited, however, due largely to constraints imposed by geography (compatible topography and hydrology). We shall argue that coupling outputs of wind farms from different regions of the Chinese coast could significantly offset the challenges associated with integrating this otherwise variable source.

The present analysis reports a statistical investigation of advantages that could be achieved in smoothing the variation of offshore wind power supply in the coastal areas of China through an optimal combination of power from geographically distributed offshore sites. A number of studies have examined the advantages of combining geographically distributed wind farms in the US and Europe (Archer and Jacobson, 2007; Huang et al., in press; Kempton et al., 2010). Kempton et al. (2010), analyzing 5 years of wind data from 11 meteorological stations distributed along the US east coast, suggested that the output of wind power from an interconnected system there would be more reliable than that from any individual location. Archer and Jacobson (2007) explored the benefits of connecting wind farms from up to 19 sites located in the US Midwest, where annual average wind speeds at 80 m above ground exceeded 6.9 m/s. They found that an average of 33%, and a maximum of 47%, of yearly average wind power from interconnected farms could provide reliable, base-load electric power. Huang et al. (in press), using 5 years of hourly assimilated wind data, showed that the high-frequency variability of wind-generated power could be significantly reduced by coupling outputs from five to ten wind farms dispersed uniformly over ten states in the middle of the US. Their analysis suggests that more than 95% of the variability of the coupled system from this region was concentrated at time scales longer than a day, allowing operators of the overall system to take advantage of multiple-day weather forecasts in scheduling projected future contributions from wind.

Building on the earlier studies, the present analysis will focus on variations of hourly wind power from 12 offshore sites distributed along the Chinese coastline (see Fig. 2), with a particular focus on the advantages that could be realized by coupling facilities distributed over three coastal economic zones (Bohai Bay, the Yangtze River Delta, and the Pearl River Delta). The total installed capacity for offshore wind power in China is projected to reach 30 GW in 2020 and 60 GW in 2030 (Wang et al., 2011). Most of the development plans for offshore wind

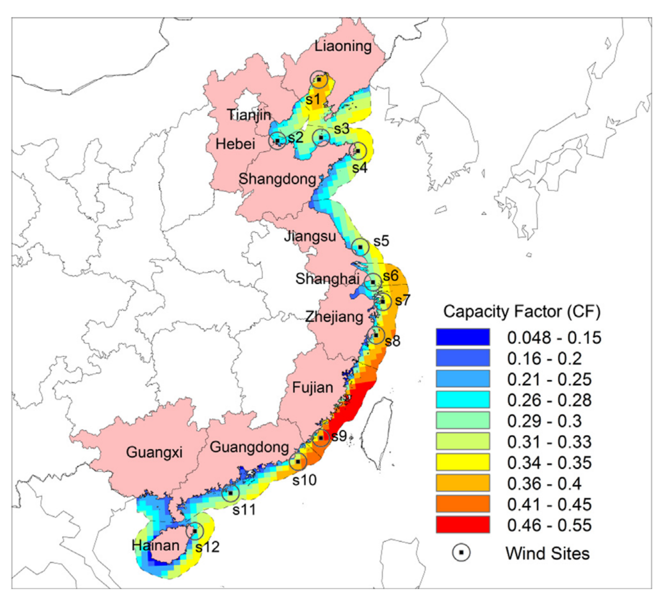

Fig. 2. Distribution of annual average capacity factors (CFs) evaluated for deployment of a network of GE 3.6 MW wind turbines within a distance of 80 km from the shoreline. The circled black dots indicate the locations of 12 sites considered in this analysis. Provinces and provincial-level municipalities with coastlines are in pink.