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Short Communication

Where, when and how much wind is available? A provincial-scale wind resource assessment for China

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HIGHLIGHTS

- We assessed China's wind resources by utilizing 10 years of hourly wind speed data of 200 sites.
- We built provincial scale wind speed profiles and develop provincial capacity factors for China.
- We found that China's wind generation could reach 2000 TWh to 3500 TWh annually.
- We observed similar temporal variation pattern of wind availability across China.

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ABSTRACT

China's wind installed capacity has grown at a remarkable rate, over 80% annually average growth since 2005, reaching 91.5 GW of capacity by end of 2013, accounting for over 27% of global capacity. This rapid growth has been the result of a domestic manufacturing base and favorable national policies. Further evolution will be greatly aided with a detailed wind resource assessment that incorporates spatial and temporal variability across China. We utilized 200 representative locations for which 10 years of hourly wind speed data exist to develop provincial capacity factors from 2001 to 2010, and to build analytic wind speed profiles. From these data and analysis we find that China's annual wind generation could reach 2000 TWh to 3500 TWh. Nationally this would correspond to an average capacity factor of 0.18. The diurnal and seasonal variation shows spring and winter has better wind resources than in the summer and fall. A highly interconnected and coordinated power system is needed to effectively exploit this large but variable resource. A full economic assessment of exploitable wind resources demands a larger, systems-level analysis of China's energy options, for which this work is a core requirement.

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1. Introduction

China's installed wind capacity has been growing at an unprecedented pace, by end of 2013, the total installed capacity has reached 91.5 GW, a 16.1 GW growth from 2012 and over 80% annually average since 2005 (CWEA, 2013; GWEC, 2014). Total wind electricity generation was 100.8 terawatt-hours (TWh) in 2012, accounting for 2% of China total electricity consumption, placing wind behind only coal and hydropower, with a calculated average capacity factor of 18.36% (CWEA, 2013; NEA, 2013). Despite this rapid progress continues, wind development in China faces challenges of grid connection (He and Morse, 2013; Lewis, 2012; Li et al., 2012; Zhao et al., 2013). According to the wind integration regulatory report in key regions released by the State Electricity Regulatory Commission, about 12.3 TWh wind electricity was lost in the curtailment in 2011, with an average curtailment rate of about 16%, resulting to a loss of 6.6 billion RMB (SERC, 2012).

The essential difficulties of integrating wind power lies in its high cross-spatial imbalance, inter-temporal variation and limited predictability (Xia and Song, 2009; Xie et al., 2011). The variability of the wind resource, impacts the availability, dispatchability, and reliability of the electricity unless larger, regional planning and synergies between intermittent and dispatachable resources are integrated into the planning grid (Loutan et al., 2009; Lu et al., 2009; Masters, 2004; Nelson et al., 2012). However, wind resources can be managed through better wind resources assessment, proper plant interconnection, integration, transmission planning, and system and market operations, among which better resources assessment is the foundation of other measures and has

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big impact on adapting the appropriate measure (DeCesaro et al., 2009; Smith et al., 2007).

The existing literature on wind resources assessment in China has focused on national level, with specific efforts examining the onshore and offshore capacity and potential. The China Meteorological Administration (CMA) has conducted three rounds of national wind resource surveys using the national weather station data, the most recent one projected a theoretical reserve of 4350 GW and a technologically feasible resource of 297 GW at 10-m height (CWEAR, 2010). Researchers in the Energy Research Institute (ERI) showed the total technological available onshore wind capacity range from 600 to 1000 GW and around 150 GW offshore (Elliott et al., 2002; Energy Research Institute (ERI), 2010; Xue et al., 2001). McElroy and Lu et al. reported that wind could satisfy all of the demand for electricity projected for 2030, and that the wind electricity resources could displace 23% of electricity generated from coal at a price of 0.4 RMB (US$0.07) per kilowatt-hour (McElroy et al., 2009). For offshore wind resources, Hong and Möller (2011) reported offshore wind energy could contribute 46% of total electricity demand by 2020 and 42% of demand by 2030 in the coastal region within China's exclusive economic zone. Those studies shed lights on overall resources but do not provide the necessary spatial resolution or give sufficient attention on the temporal variability of wind resources.

China has proposed a target to have 200 GW wind capacity (170 GW onshore and 30 GW offshore) by 2020 in the Wind Development 12th Five Year Plan, aiming to build major onshore and offshore wind bases each at 10 GW scale, including those in Xinjiang, West Inner Mongolia, East Inner Mongolia, Hebei, Jiangsu, Jilin, and Liaoning (NEA, 2012). Expanded wind development in China therefore requires deeper understanding of the resources availability, both spatially and temporally. The existing research does not provide necessary details that policy maker and wind planner need to make plan for wind energy development to address the integration of the variable resources. This paper provides a comprehensive assessment of China's onshore and offshore wind resources at provincial level with high spatial and temporal resolution.

2. Methods and data

This study combines the geographic information system (GIS) modeling and wind simulation with a large hourly data set to study the availability of China's wind resources. The hourly wind speed data from 2001 to 2010 for 200 chosen locations (Fig. 1) are obtained from 3TIER, with a total of $200 \times 8760 \times 10 = 17.52$ million data entry. Each data entry shows the wind speed, wind direction, temperature, and pressure of given hour, which are

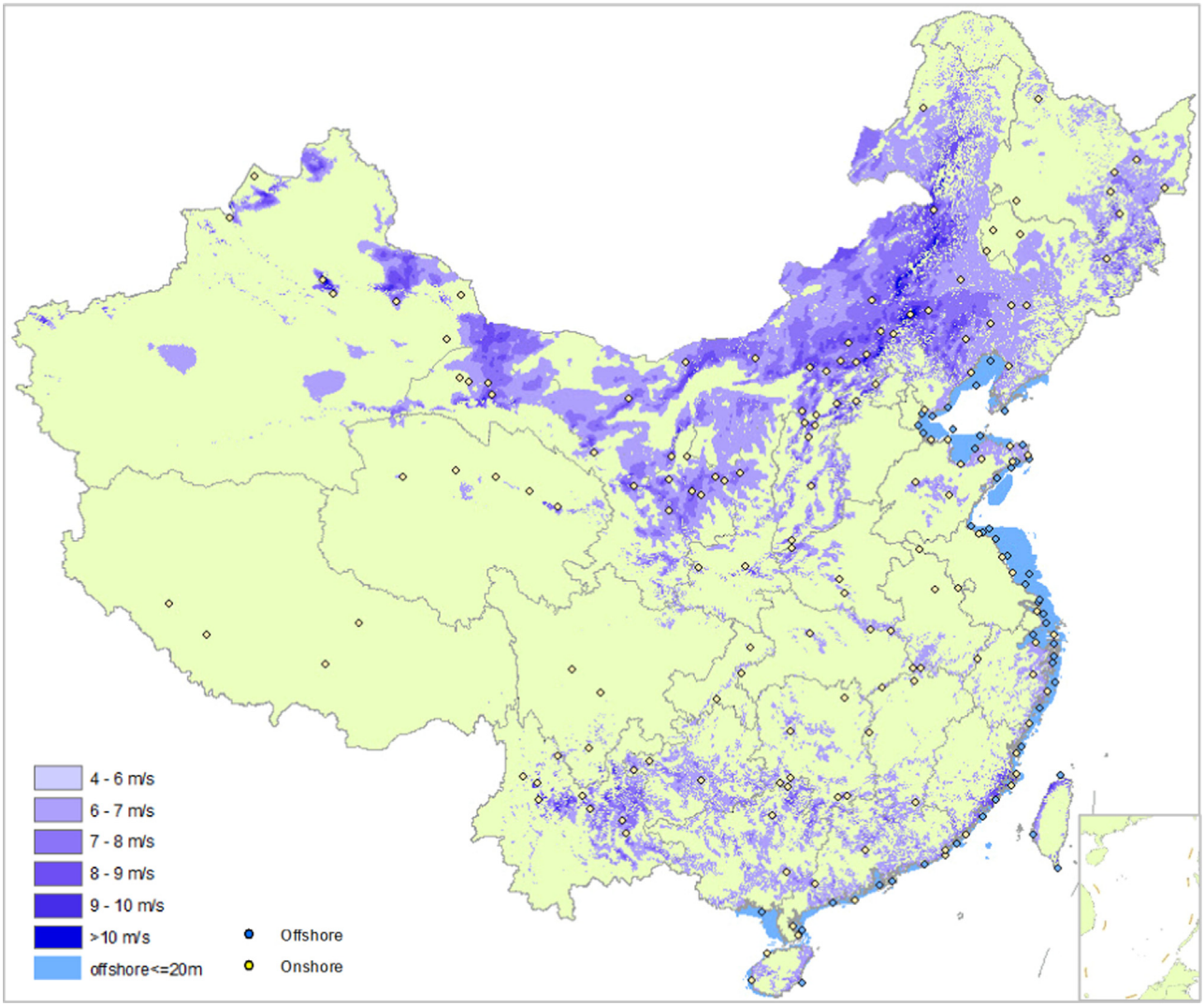

Fig. 1. China wind appropriate area map and the hourly data points.