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Short Communication

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

Gang He [a,b,*], Daniel M. Kammen [a,b,c]

[a] Renewable and Appropriate Energy Laboratory, University of California, Berkeley, CA 94720, USA
[b] Energy and Resources Group, University of California, Berkeley, CA 94720, USA
[c] Goldman School of Public Policy, University of California, Berkeley, CA 94720, USA

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

* Corresponding author at: University of California, Energy and Resources Group, 310 Barrows Hall, Berkeley, CA 94720, United States. Tel.: +1 510 642 1640; fax: +1 510 642 1085.
E-mail address: ganghe@berkeley.edu (G. He).

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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

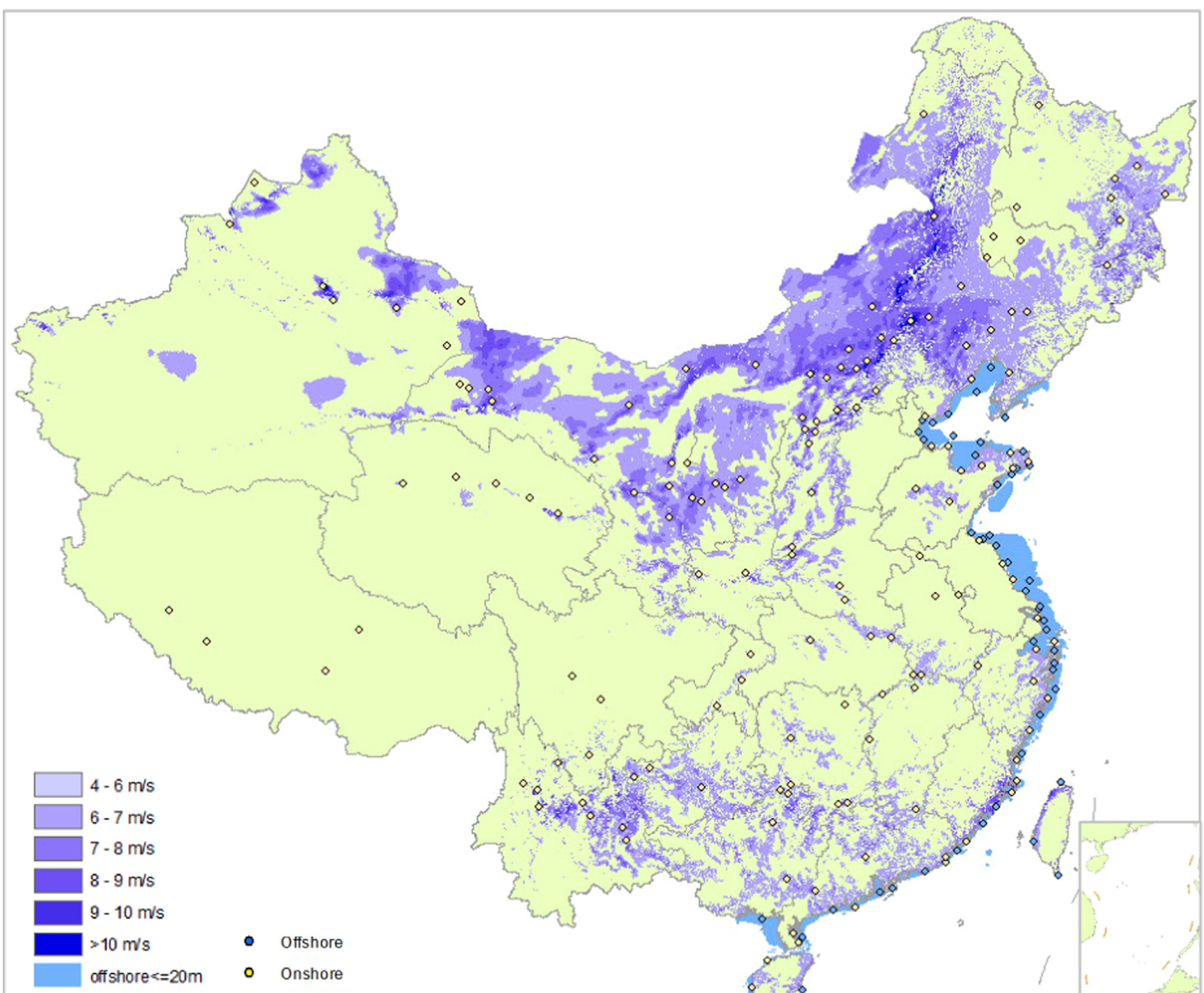

Fig. 1. China wind appropriate area map and the hourly data points.

important input to simulate wind capacity factor. The wind speeds are at 100 m height above ground, which is the average height of a 3 MW-size wind turbine. We pick those locations based on the following criteria: wind resources with average wind speed larger than 6 m/s; site conditions are appropriate for building wind projects; and spatial distribution representativeness within each province, which allows 4 to 5 locations in each of China's 31 provinces (excluding Hong Kong and Macau, Inner Mongolia is considered as East Inner Mongolia and West Inner Mongolia as they belong to two different grid systems), along with 11 provinces that have offshore resources. We created Thissen/Voronoi Polygon of those 200 sites to interpolate the area each site represents.

We accessed China's national and province-level GIS information from the National Fundamental Geographic Information System. The land use and land cover dataset and the digital elevation model (DEM) dataset are provided by the Environmental and Ecological Science Data Center for West China, both are at 1 km × 1 km resolution (Ran et al., 2010). The land use and land cover data of 2010 was compiled by Chinese Academy of Science based on county level land use survey. The General Bathymetric Chart of the Oceans (GEBCO) data is downloaded from British Oceanographic Data Center (BODC, 2010). We trimmed it with China's Exclusive Economic Zone (EEZ) to get China's offshore area. We used ArcGIS 10.0 and PostGIS to perform the spatial analysis.

We calculated the available land for wind development for each province by applying the following filters in the GIS modeling: DEM with elevation less than 3000 m and slope less than 20% (NREL, 2012), land use in the categories of woody savannas, shrublands, savannas, grasslands, barren, as defined in the land use data that are available for wind development, and average annual wind speed larger than 6 m/s (AQSIQ, 2002; Energy Research Institute (ERI), 2010). We excluded forestry, cropland, wetland, urban built-up land, water, snow and glacial, and protected land in the onshore land. For offshore space, we used bathymetry less than negative 20 m as threshold, and excluded the buffer zone of tropical cyclone paths, ship lines, and cable lines in the offshore space (Energy Research Institute (ERI), 2010; Hong and Möller, 2011). The installation capacity conversion factor ranges from 2 to 8 MW per square kilometers depends on the slope, the land availability conversion factor ranges from 30% to 90% depends on the surface condition and wind turbine layout (Energy Research Institute (ERI), 2010). The land use and slope conversion factors are usually have uncertainties depending on the technology and local condition, and this study consider a lower case and upper case for the conversion factors as listed in Table 1.

The potential wind capacity is calculated from below,

$$PC = \sum l_i \times sf_i \times lf_i$$

where PC: potential capacity; l_i: land area of land use type of grid i. The selection criteria are listed as the following: Wind speed: $v_{avg} \geq 6$ m/s, Elevation: $E \leq 3000$ m in lower case or $E \leq 3500$ m in higher case, Bathymetry: $B \geq -20$ m, Slope: $s \leq 20\%$; sf_i and lf_i are the slope factor and land use factor of grid i specified in Table 1. All calculation are applied at 1 km × 1 km grid and then using zonal statistics by province. By applying the land selection criteria in the GIS model, the land that is appropriate for wind development for each province is shown in Fig. 1. The most area lays in northern China and along the coastal offshore area.

The CF of each location is simulated with the hourly wind speed values based on the power curves of representative newly installed turbine sizes in 2012, correcting with air density. The share of turbine size of larger than 2.5 MW, 2 MW, 1.5 MW, less than 1 MW, and other sizes are 6.6%, 26.1%, 63.69%, 1.06% and 2.55% respectively, as reported in 2012 (Li et al., 2013). 2 MW size turbine is considered as mainstream size for new installation. For offshore wind, the newly installed turbines are shared by 2.5 MW and 3 MW size turbines,

Table 1
GIS model thresholds and capacity conversion factors.
Source: The lower case of onshore assumptions are from Energy Research Institute (ERI), 2010. 2030 China wind development outlook: the feasibility study of meeting 10% of electricity demand. Energy Research Institute, Beijing. pp:28–49. The upper case are based on expert interview in the field and for comparison use. Offshore land use factor is from Hong and Möller, 2011.

Cases		Threshold/capacity conversion index		
		Onshore		Offshore
		Lower case	Upper case	
Elevation/bathymetry		3500 m	3000 m	−20
Wind speed threshold		6 m/s	6 m/s	6 m/s
Slope α (%) factor	$\alpha \leq 2$	5 MW/km^2	8 MW/km^2	4 MW/km^2
	$2 \leq \alpha \leq 3$	3 MW/km^2	6 MW/km^2	
	$3 \leq \alpha \leq 4$	2 MW/km^2	4 MW/km^2	
	$4 \leq \alpha \leq 20$	0 MW/km^2	2 MW/km^2	
Land use factor	Mixed forest	30%	50%	64%
	Shrublands	65%	75%	
	Savannas	65%	75%	
	Grassland	80%	90%	
	Barren	80%	90%	

popular sizes for newly built offshore wind projects in China (Li et al., 2012; Zhao et al., 2013). In this study, we applied the power curves of a representative Goldwind 2 MW size wind turbine for onshore CF simulation, and a representative Vestas 3 MW size wind turbine for offshore CF simulation.

$$\text{Capacity factor} = \frac{\text{reference output}}{\text{rated capacity}}$$

3. Results

3.1. Average capacity factor, potential capacity and output

The results of the study are presented in terms of CF, potential capacity and output by resource type: onshore and offshore and by province. The annual average CFs of each province are comparatively stable across years during the study period, see Fig. 2. Therefore, ten years average CF is representative for the long-term CF for each province.

The ten-year average CFs of onshore and offshore wind for each province are shown in Table 2. Xizang (Tibet), Fujian, Hebei, East Inner Mongolia, West Inner Mongolia, Shanghai, and Shanxi have better onshore wind availability compared to other onshore provinces, and Zhejiang, Shanghai, Fujian, Hainan, Liaoning, and Jiangsu have better offshore wind availability, each with an average CF bigger than 0.2.

China has a national total potential wind capacity from 1300 GW to 2300 GW and national potential annual wind output between 2000 TWh and 3500 TWh in the lower case and upper case respectively, assuming all the land appropriate for wind projects is developed.

The overall calculated average capacity factor based on hourly data including onshore and offshore is at 0.18, which is lower compared to what has been reported at 0.23 based on annual output (Cyranoski, 2009). Capacity factors that calculated from yearly output do not reflect the real availability of a country's wind resources because they do not capture the spatial imbalance and temporal variation. A low observed overall capacity factor may be due to unusually low winds that are below their long term potential. This phenomena is also observed in European wind CF studies (Boccard, 2009). This difference shows the spatial and

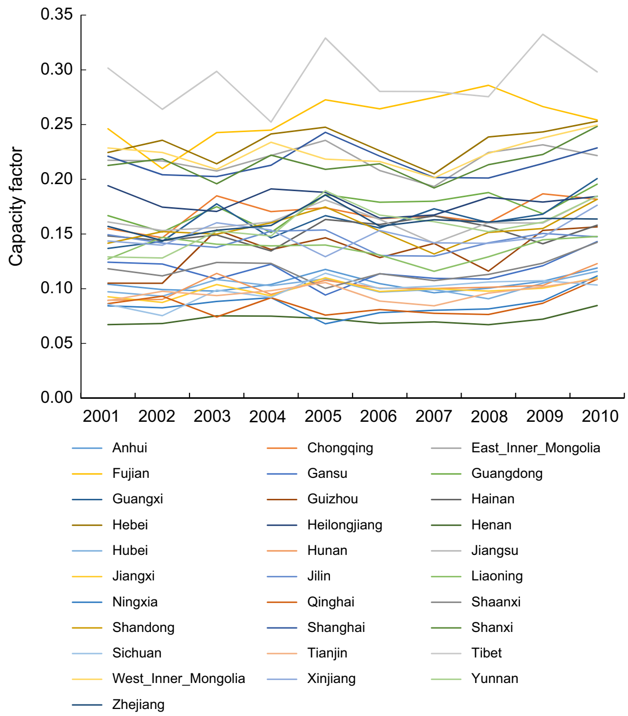

Fig. 2. Annual average capacity factor by province 2001–2010.

temporal characteristics of wind resources is key to understand the availability and integration of variable wind resources.

3.2. *Spatial variation of provincial wind availability*

The wind resources potential varies across provinces in China. Provinces with large wind capacity potentials are most located in the northern China for onshore and along the coast for offshore. For offshore wind, Jiangsu has the largest potential capacity, more than 100 GW, following by Shandong, Liaoning, Zhejiang, Guangdong, Fujian, Guangxi, Shanghai, Hebei, Hainan, and Tianjin.

For onshore wind, Table 2 shows wind capacity potential at provincial level varies at great scale, from less than 1 GW to near 600 GW. This mainly due to the imbalance of wind power distribution, overlaid with land use, elevation, slope and bathymetry, and other surface conditions.

In the upper case, Xinjiang, West Inner Mongolia, East Inner Mongolia, and Gansu each has a potential capacity more than 100 GW. West Inner Mongolia has a capacity potential of 350 GW, combined with 210 GW in East Inner Mongolia, together make Inner Mongolia the province with the largest capacity potential, equivalent with Xinjiang and following by Gansu. In the lower case, only Xinjiang, East Inner Mongolia, and West Inner Mongolia are with a capacity more than 100 GW. The Three-North regions, including Northwest (Xinjiang, Shaanxi, Ningxia, Qinghai, and Gansu), Northeast (Heilongjiang, Jilin and Liaoning) and North

Table 2
Average capacity factor and potential capacity and output of onshore and offshore wind by province 2001–2010.

Province	Onshore potential					Offshore potential		
	Avg. CF	Capacity (GW) (lower)	Output (TWh) (lower)	Capacity (GW) (upper)	Output (TWh) (upper)	Avg. CF	Capacity (GW)	Output (TWh)
Anhui	0.1050	3.31	3.04	9.03	8.30			
Beijing	0.1044	0.37	0.34	1.59	1.45			
Chongqing	0.1690	1.46	2.16	5.70	8.44			
East Inner Mongolia	0.2178	102.55	195.67	210.10	400.88			
Fujian	0.2562	2.84	6.37	12.20	27.38	0.2240	28.05	55.03
Gansu	0.1168	54.99	56.27	120.85	123.66			
Guangdong	0.1742	6.88	10.50	19.05	29.07	0.1890	51.71	85.62
Guangxi	0.1629	13.85	19.76	36.40	51.93	0.1196	26.59	27.86
Guizhou	0.1342	8.87	10.42	26.28	30.89			
Hainan	0.1520	2.28	3.04	5.04	6.71	0.2237	10.36	20.30
Hebei	0.2329	5.78	11.79	17.86	36.44	0.1329	24.12	28.08
Heilongjiang	0.1797	37.54	59.10	85.81	135.10			
Henan	0.0720	2.22	1.40	7.00	4.42			
Hubei	0.1018	4.98	4.44	15.71	14.02			
Hunan	0.1024	10.12	9.08	27.93	25.05			
Jiangsu	0.1622	0.44	0.63	0.90	1.28	0.2010	107.62	189.54
Jiangxi	0.0993	8.67	7.54	22.48	19.55			
Jilin	0.1435	13.29	16.70	30.09	37.82			
Liaoning	0.1362	5.58	6.66	14.07	16.79	0.2049	60.58	108.75
Ningxia	0.0855	6.42	4.81	13.76	10.31			
Qinghai	0.0852	28.47	21.24	80.41	59.98			
Shaanxi	0.1177	13.55	13.97	35.06	36.16			
Shandong	0.1551	4.23	5.75	8.81	11.97	0.1965	76.54	131.73
Shanghai	0.2150	0.01	0.02	0.07	0.13	0.2241	24.30	47.72
Shanxi	0.2149	7.21	13.57	22.35	42.07			
Sichuan	0.0985	2.06	1.78	12.98	11.20			
Tianjin	0.0964	0.09	0.08	0.17	0.14	0.1083	5.56	5.27
Tibet (Xizang)	0.2912	0.10	0.26	0.83	2.12			
West Inner Mongolia	0.2243	189.00	371.32	351.90	691.37			
Xinjiang	0.1486	285.14	371.30	567.60	739.11			
Yunnan	0.1574	8.13	11.21	33.59	46.30			
Zhejiang	0.1607	2.22	3.12	9.44	13.29	0.2332	53.84	110.00
Average/Total	0.1771	832.65	1243.35	1805.06	2643.34	0.1970	469	810

Note: Those provinces without offshore resources are left blank.

China (Inner Mongolia, Hebei, Shanxi, Beijing and Tianjin) in total account for 90% and 85% of national onshore capacity, in the lower and upper cases, respectively. The spatial variation across China and the concentration in northern part of China are the fundamental geographical features of the wind recourses.

Potential wind output has similar geographic pattern, but slightly different order, as the capacity potential and CF are not always coupled with each other. Inner Mongolia and Xinjiang are the top provinces which have the potential annual output larger than 100 TWh in the lower case. In the upper case, this list expands to Heilongjiang and Gansu. Inner Mongolia, Xinjiang, Heilongjiang and Gansu are the top potential producers, together account for 91% and 88% of national total potential onshore output in the lower and upper case, respectively.

3.3. Temporal variation of provincial wind availability

We examined the inter-hourly wind variability within a day, the inter-daily wind variability within a month, and the inter-monthly wind variability within a year for all the 200 chosen locations. The inter-hourly and inter-daily variability are extremely disperse and does not show any regular trend, however, both the onshore and offshore wind resources show regular inter-monthly (seasonal) variation pattern, due to the monsoon wind pattern in East Asia (see Fig. 3 and Fig. 4).

For onshore wind, all provinces have better availability during spring and winter than in summer and autumn, but some provinces, for example, Guangxi, Shanghai, and Zhejiang have a small increase in July. The highest monthly CF reaches as high as 0.5446 in Xizang in January, and the lowest reaches 0.0318 in Tianjin in August, the difference between the highest of lowest of the same province can as high as 0.48 in Xizang, and the maximum monthly average CF is more than 8 times of the minimum. Jiangxi has the minimum differences between extreme values, but has comparatively low average CF of 0.0994.

For offshore wind, Fujian, Zhejiang, Hainan have superior availability in the Spring and Winter, while Shanghai has the best availability during the Summer. Similar to onshore wind, all provinces have better availability during the Spring and Winter than in Summer and Autumn, but some provinces, for example, Zhejiang, Shanghai, and Jiangsu have a small increase in July. The highest monthly average CF researches 0.4254 in Hainan in November, and the lowest 0.0354 in Tianjin in August. The biggest difference between the highest and the lowest in the same province is 0.3208 in Hainan, and the maximum monthly average CF in more than 5 times of the minimum. Shanghai has the minimum difference between extreme values.

The regional differences and spatial variability of wind resources show national coordination is needed to develop transmission corridors to transmit wind power out of the wind rich areas. However, as provinces follow similar seasonal variability pattern, inter-provinces coordination might provide less value than expected at seasonal time scale, back up capacity or storage assets has to be in place in order to tackle such variation and keep the power system reliable. The integration and optimization of different energy resources, such as wind and natural gas fired power, wind and solar, wind and storage, wind and hydro, other flexible sources, and demand response/demand side management will be sentential to deal with such temporal variation pattern.

3.4. Potential contribution of wind generation

We compared the provincial potential power output with projected provincial demand of 2030 and showed the potential share of wind power in total electricity demand in each province. We use electricity demand of 2030 as it is the best available year

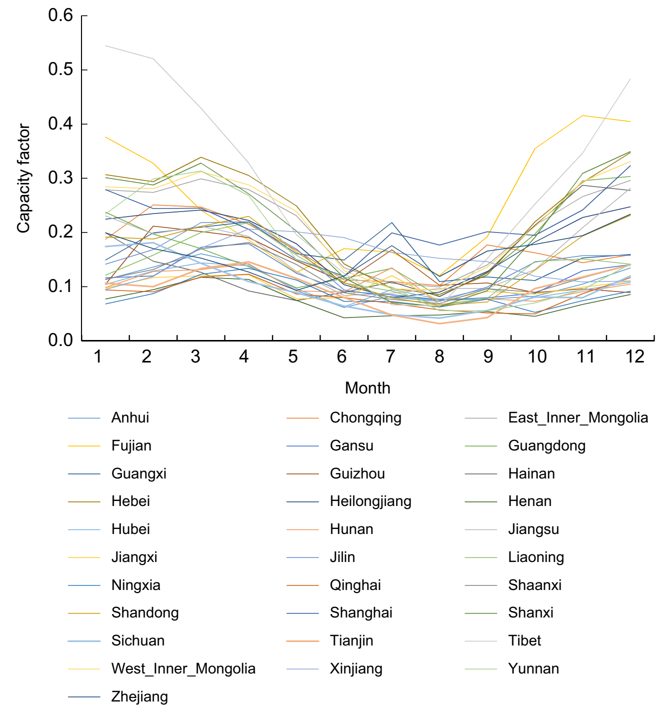

Fig. 3. Monthly average onshore wind capacity factor 2001–2010.

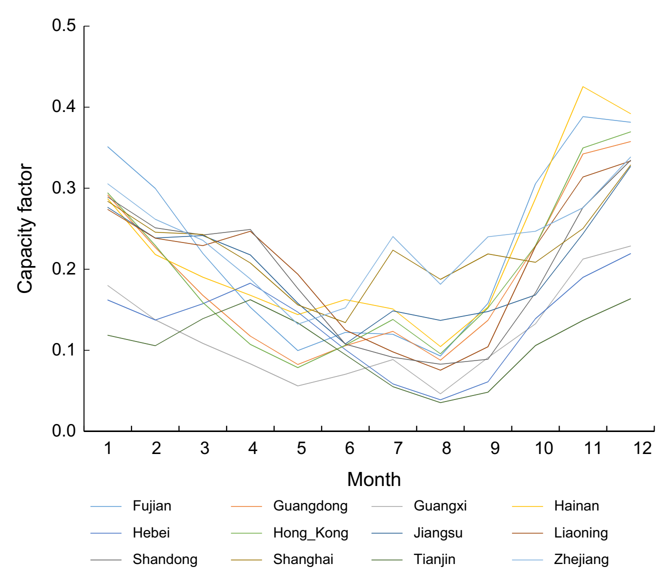

Fig. 4. Monthly average offshore wind capacity factor 2001–2010.

with projected provincial electricity demand reported by the Electricity Supply and Demand Lab in the State Grid Energy Research Institute (Hu et al., 2011). Wind energy development and the total energy demand in each province have many uncertain factors, for example, economic development, competition and integration from other sources, investments and costs, the share of wind in total energy consumption is therefore an indicative number to show the potential contribution of wind can possibly achieve, and a schematic balance sheet of wind energy supply and demand.

Seen from Table 3, wind share at provincial level varies at great scale, from 1% to 420%, which reiterates the geographic variability of wind resources. In the upper case, West Inner Mongolia, Xinjiang, and East Inner Mongolia each generates more than what it needs therefore transmission is needed to transfer the extra

Table 3
Potential share of wind generation by province in 2030.

Province	Demand 2030 (TWh)	Total output (lower)(TWh)	Share (%)	Total output (upper)(TWh)	Share (%)
Anhui	240.00	3.04	1	8.30	3
Beijing	133.20	0.34	0	1.45	1
Chongqing	171.10	2.16	1	8.44	5
East Inner Mongolia	272.44	195.67	72	400.88	147
Fujian	308.50	61.40	20	82.40	27
Gansu	205.10	56.27	27	123.66	60
Guangdong	815.10	96.12	12	114.69	14
Guangxi	254.30	47.61	19	79.78	31
Guizhou	218.00	10.42	5	30.89	14
Hainan	47.40	23.34	49	27.01	57
Hebei	676.90	39.87	6	64.52	10
Heilongjiang	153.50	59.10	39	135.10	88
Henan	614.20	1.40	0	4.42	1
Hubei	341.70	4.44	1	14.02	4
Hunan	298.70	9.08	3	25.05	8
Jiangsu	791.50	190.16	24	190.82	24
Jiangxi	165.30	7.54	5	19.55	12
Jilin	139.70	16.70	12	37.82	27
Liaoning	409.30	115.40	28	125.53	31
Ningxia	141.30	4.81	3	10.31	7
Qinghai	96.90	21.24	22	59.98	62
Shaanxi	233.50	13.97	6	36.16	15
Shandong	760.30	137.48	18	143.70	19
Shanghai	232.80	47.74	21	47.85	21
Shanxi	370.30	13.57	4	42.07	11
Sichuan	366.50	1.78	0	11.20	3
Tianjin	136.70	5.35	4	5.42	4
Tibet (Xizang)	7.30	0.26	3	2.12	29
West Inner Mongolia	163.46	371.32	227	691.37	423
Xinjiang	244.10	371.30	152	739.11	303
Yunnan	238.90	11.21	5	46.30	19
Zhejiang	596.80	113.13	19	123.29	21
Total/ Average	9845	2053	21	3453	35

energy to the coastal demand centers. Inner Mongolia at the upper case generates more than 4 times of the projected demand which tops all provinces. Xizang and Qinghai have relatively high average CFs but with the land at high elevation, greater than 3000 m, are excluded in the assessment. Nationwide, potential wind annual output could reach 2000 TWh and 3500 TWh in the lower case and upper case, respectively.

3.5. Sensitivity analysis and uncertainties

We conducted sensitivity analysis on four key assumptions of the GIS model: the 6 m/s wind speed threshold, the 20% slope threshold, the 3000 m elevation threshold, and the 20 m of bathymetry threshold. We studied the relations of those factors with the potential capacity, and plotted them in Fig. 5. The results in the upper case and lower case are quite similar as those four factors follow the same change pattern.

All four factors are following non-linear relations with the capacity potential. The capacity potential are more sensitive to the 6 m/s average annual wind speed threshold and the 20 m bathymetry threshold, but less sensitive to the 20% slope and 3000 elevation threshold.

In addition, there are many uncertainties related to this study. The inter-annual variation in some sites are not trivial, and should be incorporated into long-term projection. Technology advancement might make it possible to harvest lower speed wind, at places with steeper slope, in land with less favorable surface

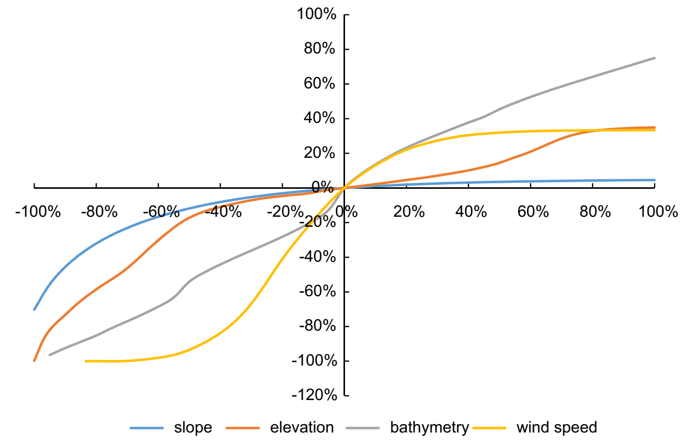

Fig. 5. The sensitivity analysis of key assumptions to the capacity potential.

conditions, and deeper bathymetry offshore wind resources, therefore the results of this analysis need update in the future as technologies develop.

4. Conclusion and discussion

China's wind installed capacity has grown at a remarkable rate, reaching 91.5 GW of capacity by end of 2013. Existing research has been focusing on national scale and does not provide the necessary spatial resolution or give sufficient attention on the spatial and temporal variation of wind availability. Given wind as an inherently variable resource, China's ambitious wind development plan will be greatly aided with a detailed wind resource assessment that identifies total resources, spatial availability, and seasonal and daily variability across China. Knowing where, when and how much wind is available at provincial level can help the researchers and policy makers on wind development planning and integration.

Combining methods of GIS modeling and wind CF simulation, we utilized 200 representative locations for which 10 years of hourly wind speed data exist to study provincial capacity factor from 2001 to 2010, and to build wind availability profiles. From these data we found that China could have a potential wind capacity from 1300 GW to 2300 GW, and annual wind output could reach 2000 TWh to 3500 TWh. The calculated average capacity factor is 0.18, which is lower compared to what has been reported.

This study extends the exiting research by investigating wind availability in China at higher spatial resolution and temporal resolution so to understand the spatial and temporal availability of wind resources across China. The results of this study can be used to facilitate local and national wind development plans and can be also utilized by developers and regulators to develop strategies on wind integration. Table 4 listed the comparison of this study with other major similar research in their methods, data and key findings.

While spatial variation demands highly interconnected and coordinated power system, similar temporal variation pattern restricted the effectiveness of such a system. We studied the diurnal and seasonal features of the wind availability at provincial level and found similar seasonal variation pattern between provinces, which indicates the difficulties to integrate wind resources through regional coordination, and back up capacity or storage assets has to be in place in order to incorporate such variation. The diurnal and seasonal variability demand a larger, systems-level analysis of China's energy options with more careful investigation of

Table 4
Comparison to other similar research.

Study	Results			Methods	Data
	Capacity potential	Average CF	Total generation potential		
This study (2014)	Onshore: 800–1800 GW Offshore:470 GW	0.18	Total:2,000–3,500 TWh	GIS model/CF simulation	3TIER hourly data WESTDC
China Meteorological Administration (2006)	Onshore: 297 GW	N/A	N/A	Wind Energy Simulation Toolkit	Meteorological data
Energy Research Institute (ERI) (2010)	Onshore: 600–1000 GW Offshore: 150 GW	N/A	N/A	Numerical Simulation	SWEAR
McElroy et al. (2009)	N/A	0.23	Technical: 24,700 TWh Economic:6,960 TWh	GIS/ Financial model	GEOS-5
Hong and Möller (2011)	Offshore: 570 GW, 848 GW, and 1007 GW by 2010, 2020 and 2030	0.375	Offshore: 637 TWh	GIS model	SWERA

Note: WESTDC refers to the cold and Arid Regions Science Data Center at Lanzhou of China. SWERA refers to the Solar and Wind Energy Resource Assessment project for the United Nations Environment Program. GEOS-5 refers to the Goddard Earth Observing System Model, Version 5.

technical and economic availabilities and the role of inter-province transmissions, for further research, we will examine the implications of the wind variability and availability in the context of an overall energy strategy for China.

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