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

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ABSTRACT

Integrating variable energy resources, notably solar and wind, requires better understanding of where, when and how much of variable resources are available. China's ambitious solar energy development goal will be greatly facilitated by the resources assessment at higher spatial and temporal resolution. We utilized 10-year hourly solar irradiation data from 2001 to 2010 from 200 representative locations to develop provincial solar availability profiles. We found that China has a potential stationary solar capacity from 4700 GW to 39300 GW, distributed solar about 200 GW, and the annual solar output could reach 6900 TWh to 70100 TWh. Resources are most concentrated in northwest provinces, topped by Inner Mongolia, Xinjiang and Gansu. The challenge of solar development in China is integration rather than resources. The spatial and temporal variation of the solar resource show an efficient, robust, and interconnected national grid and sound energy planning would be necessary to facilitate the integration of these vastly available but variable solar resources.

1. Introduction

China's solar power installed capacity has been growing at an unprecedented pace. China's solar photovoltaic (PV) accumulated installed capacity has reached 28.05 gigawatts (GW) by the end of 2014, including 23.38 GW of stationary PV and 4.67 GW of distributed PV, resulting in a 30-fold increase of capacity from 0.9 GW in 2010 [1,2]. The total solar electricity generation was 25 TWh in 2014, accounting for about 0.45% of China's total electricity consumption in the same year [3]. The share of solar energy in total generation is still small, however, the rapid growth and expanding installation of solar power has increasingly posed a real challenge for the grid [4,5].

Solar, similar to wind, is referred to as a variable energy resource because its electricity production varies based on the availability of sun. Some aspects of solar variability are predictable, for example, sunrise and sunset. Other aspects, such as intermittent cloud cover or other types of weather change, are much less so. The spatial imbalance and temporal variation make solar generation difficult to integrate [6]. The variability of the solar resource, impacts the availability, dispatchability, and reliability of the electricity [7]. Better solar resources assessment is fundamental for proper plant placement, transmission interconnection planning, system integration, and market operations.

The existing literature on solar resources assessment in China has focused on the theoretical potential at national level or a specific region, without giving the spatial and temporal variation and availability. Zhou et al. (2010) used the daily irradiation and sunshine duration data of 163 meteorological stations in Shaanxi, Qinghai, Gansu, and Xinjiang and provided a spatial distribution of solar radiation in those provinces [8]. A few other provinces have conducted resource assessments for distributed solar, for example, Jiangsu and Shandong [9]. Those studies shed lights on overall resources assessment, but do not provide the necessary spatial resolution or give sufficient attention on the temporal variability of solar resources.

China has proposed a target to have 21 GW solar power capacity

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(11 GW station and 10 GW distributed) by 2015 and 50 GW capacity (23 GW station and 27 GW distributed) by 2020 in the Solar Power Development 12th Five Year Plan [10]. It was then upgraded to 70 GW by 2017 and 100 GW by 2020 to boom domestic installation and cut air pollution, with a focus in Jing-Jin-Ji region (Beijing, Tianjin, and Hebei), Yangtze River Delta and Pearl River Delta area where air pollution are severe, and Qinghai, Xinjiang and Gansu where solar and land are abundant [11,12]. To achieve those ambitious targets and high penetration of solar power requires deeper understanding of the resources availability, both spatially and temporally. He and Kammen (2014) conducted a research on the availability of wind resources at provincial level [13]. This paper provides a comprehensive assessment of China's solar resources at provincial level with hourly solar irradiation data.

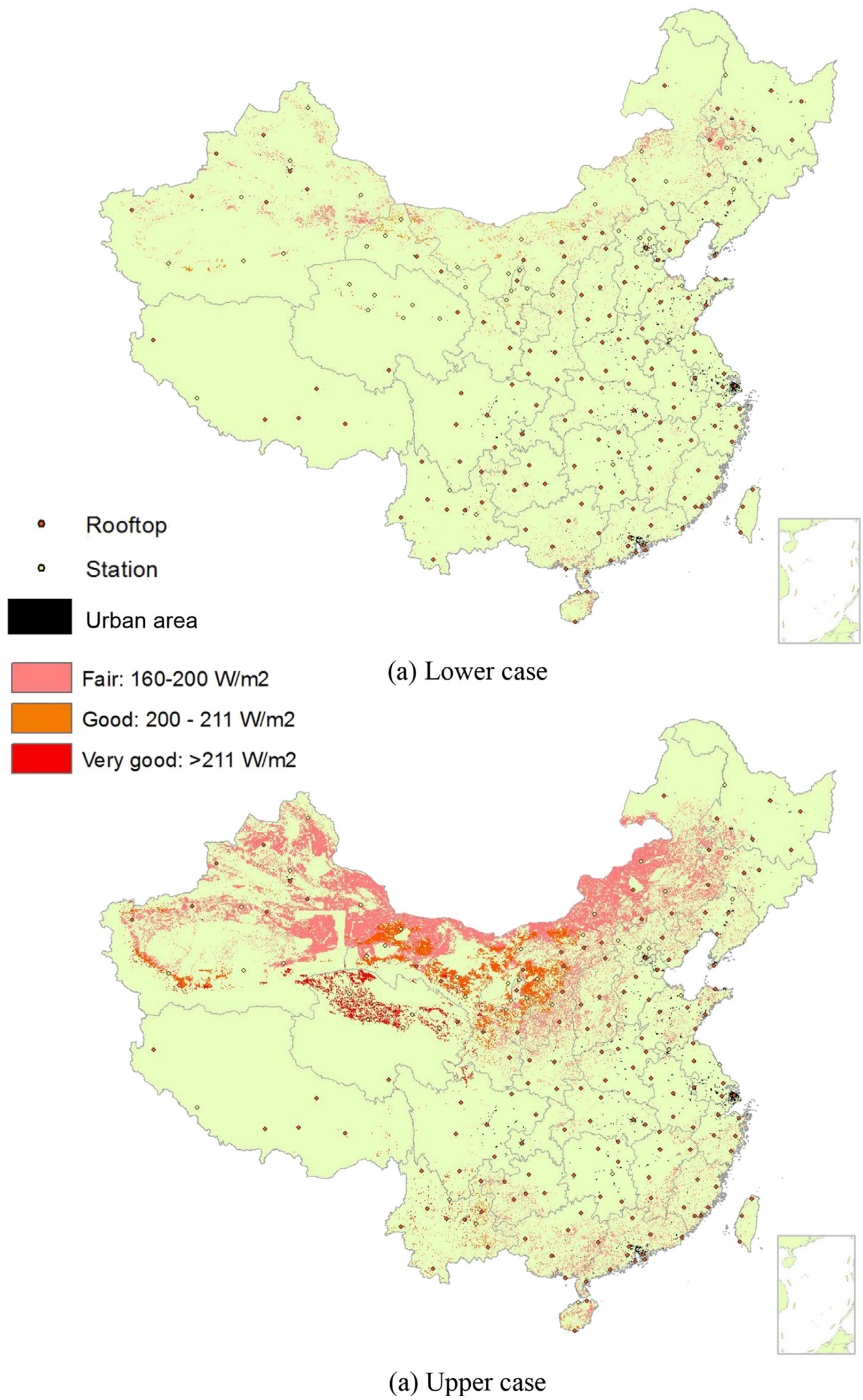

Fig. 1. China solar appropriate area map in the lower and upper case.

Table 1
Solar resources classification in China.

Class	Total solar irradiation	Average GHI	Diurnal peak daylight hours	Resource
1	>6660 MJ/m^2·a >1850 kW h/m^2·a	>211 W/m^2	>5.1 h	Very good
2	6300–6660 MJ/m^2·a 1750–1850 kW h/m^2·a	200–211 W/m^2	4.8–5.1 h	Good
3	5040–6300 MJ/m^2·a 1400–1750 kW h/m^2·a	160–200 W/m^2	3.8–4.8 h	Fair
4	<5040 MJ/m^2·a <1400 kW h/m^2·a	<160 W/m^2	<3.8 h	Poor

Note: Resource in the "Poor" category is not recommended for solar development. Source: CMA. Assessment Method for Solar Energy. Beijing: China Meteorological Administration; 2008 [15].

Table 2
Setting of the upper case and lower case.

Cases	Lower case	Upper case
Elevation	3500 m	3000 m
Slope threshold	1%	3%
Land use filter	Exclude all desert land	Exclude shifting sandy land and semi-shifting sandy land; Include fixed sandy land, semi-fixed sandy land and Gobi desert

Source: The slope threshold is from NREL [19].

2. Methods and data

This study combines the geographic information system (GIS) modeling and solar simulation with a large hourly data set to study the availability of China's solar resources. The hourly solar irradiance data from 2001 to 2010 for 200 chosen locations (Fig. 1) are obtained from 3TIER, with a total of 200 × 8760 × 10 = 17.52 million data entry. Each data entry shows the basic location information, hourly Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI), and Diffuse Horizontal Irradiance (DHI). We matched the locations with the hourly weather data from Chinese Standard Weather Data (CSWD) [14].

We pick those locations based on the following criteria: solar resources with an average GHI larger than 160 W/m^2, which is the threshold of GHI that are fit for solar project development recommended by China Meteorological Administration (see Table 1) [15]; site conditions are appropriate for building solar projects (independent to the wind sites); and spatial distribution representativeness within each province, which allows 4 to 6 locations in each of the 31 provinces in mainland China (excluding Hong Kong and Macau; Inner Mongolia is considered as East Inner Mongolia and West Inner Mongolia as they belong to two different regional grid systems). We created Thissen/Voronoi Polygon within province boundary of those 200 sites and applied Kriging method to interpolate the area that each site represents.

We accessed China's national and province-level GIS data 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 Cold and Arid Regions Science Data Center at Lanzhou, both are at 1 km × 1 km resolution [16]. The land use and land cover data of 2010 was compiled by of Chinese Academy of Science based on county level land use survey. The desert land use map is provided by "Environmental & Ecological Science Data Center for West China, National Natural Science Foundation of China" (http://westdc.westgis.ac.cn). The urban area GIS layer, where the commercial and residential solar PV locate, is obtained from Beijing City Lab [17]. We downloaded the protected land GIS layer from World Database on Protected Areas (WDPA) (http://protectedplanet.net/). We used PostgreSQL for data management and ArcGIS 10.0 and PostGIS to perform the spatial analysis.

We calculated the available land for solar development for each province by applying the following filters in the GIS modeling: DEM with elevation less than 3000 m and slope less than 1% in the lower case, and 3500 m and 3 present in the upper case [18], land use in the categories of barren land, as defined in the land use data that are available for solar development. We excluded forestry, cropland, wetland, water, woody savannas, shrublands, savannas, grasslands, snow and glacial, and protected land for stationary PV. Desert land is assumed into a lower case and an upper case by type of sandy land (Table 1). We interpreted urban construction land to

Table 3
Total land use requirements by solar technology.

Technology		Land requirement (U.S.)		Land requirement (China)
		Average area requirement (acres/MW)	Land conversion factor (MW/km^2)	Land conversion factor (MW/km^2)
(a)				
Central PV	Fixed	7.5	33	30
	1-axis	8.3	30	
	2-axis CPV	8.1	31	
CSP	All	10	25	25
	Trough	9.5	26	
	Tower	10	25	
	Dish Stirling	10	25	
	Linear Fresnel	4.7	53	

Technology	Average space requirement (m^2/kW)	Space conversion factor (kW/m^2)
(b)		
Residential PV	12	0.083
Commercial PV	12	0.083

Source: The capacity weighted average area requirement with project larger than 20 MW for U.S. are extracted from Ong et al., 2013 [19], and are for comparison purpose.

the roof space that potentially available for commercial and residential solar PV installation. The installation capacity conversion factor in the U.S. ranges from 7.5 to 10 acres per MW (25–33 MW/km^2), depending on the technology, array configuration, and tracking technologies [19]. The land use conversion factors usually have uncertainties depending on the technology and local condition, and Chinese sites are usually denser as land resource is scare in China. In this study, we use the average 30 MW/km^2 for Central PV, and 25 MW/km^2 for CSP based on interview with solar project developers (Table 3).

The potential solar capacity is calculated from below,

$$PC = \sum l_i \times lf_{ss} + \sum l_i \times lf_{ds}$$

where PC: potential capacity; l_i: land area of land use type of grid i. The selection criteria for stationary solar land are listed as the following: Solar radiation: $GHI_{avg} \geq 160\ W/m^2$, Elevation: $E \leq 3000$ m in the upper case and $E \leq 3500$m in the lower case, Slope: $s \leq 1\%$ in the lower case and $s \leq 3\%$ in the upper case; lf_{ss} and lf_{ds} are the land use factors of stationary solar and distributed solar as specified in Table 2. Stationary solar technologies compete for land which means only one technology can be built in grid i; distributed solar does not compete for space as residential and commercial PV use different rooftop space where appropriate. We considered 6 types of key solar power technologies: stationary solar technology including solar PV, concentrate solar power (CSP) with 6 h of storage, CSP without storage, and distributed solar including commercial and residential PV. This study does not include solar thermal technologies. All calculation are applied at 1 km × 1 km grid and then summarized by zonal statistics at provincial level. By applying the land filter criteria in the GIS model, the land that are appropriate for solar development in the lower case and upper case for each province are shown in Fig. 1.

The CF of each location by technology is simulated with hourly solar irradiation values using the System Advisor Model (SAM) developed by National Renewable Energy Laboratory (NREL) (http://sam.nrel.gov) [20]. Using the power curve of most commonly installed solar panel modules [1], combining standardized setting of inverter and array setting, SAM is able to use the irradiation data, dry bulb temperature, and wind speed in the weather file to simulate the output of specific solar capacity at designated locations. The CF is then calculated by the simulated output and the solar capacity at each location. We used SamUL Script to run the bulk simulation.

3. Results

3.1. Average capacity factor, potential capacity and output

We calculated the CF, potential capacity and output by technology type in each province. We choose the central PV as a representative technology to show the results in chart. The annual

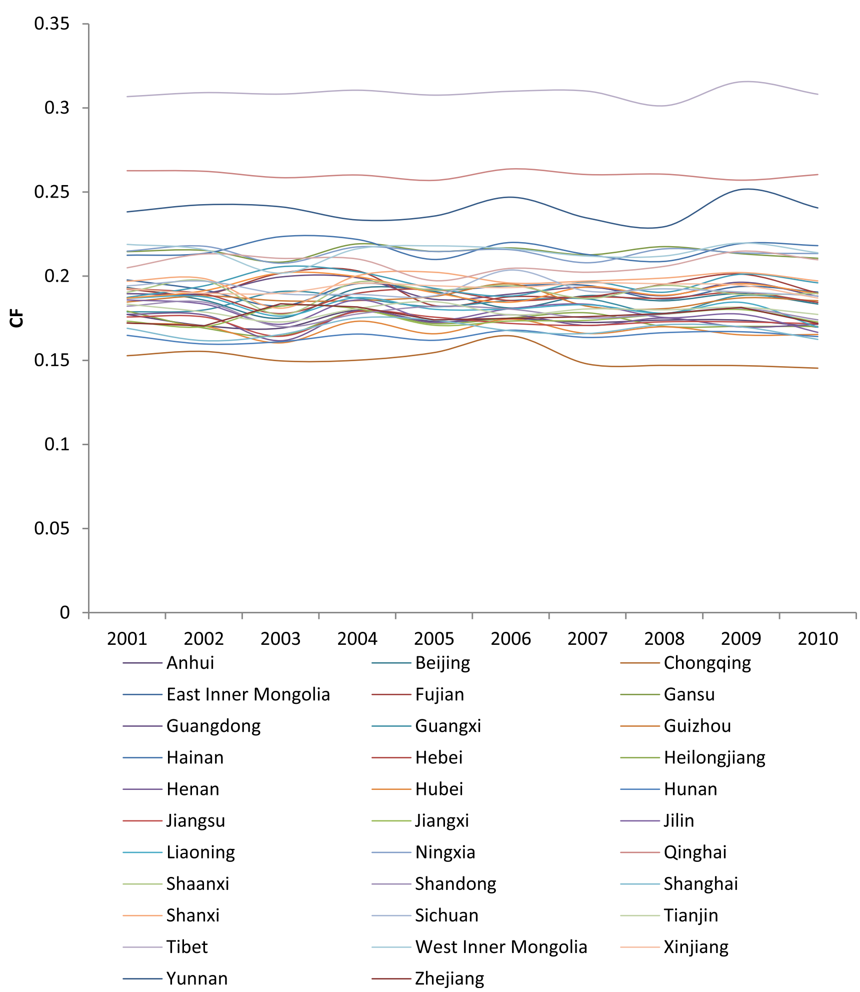

Fig. 2. Annual average central PV capacity factor by province 2001–2010.

average CFs of each province are comparatively stable across years during the study period (Fig. 2). Therefore, ten years average CF is representative for the long-term CF in each province and is used in the calculation of potential output.

The ten-year average CFs of central PV, CSP, residential PV and commercial PV for each province are shown in Table 3. Xizang (Tibet), Yunnan, Hainan, West Inner Mongolia, Gansu, and Ningxia have comparatively larger CFs compared to provinces, they are either locate in the west at high elevation or in the south with better insolation, each has an average CF bigger than 0.2 in the stationary solar. Central PV and CSP have larger CFs than residential and commercial PV.

China has a national total potential central PV capacity from 4700 GW to 39300 GW and national potential annual solar output between 8000 TWh and 69900 TWh in the lower case and upper case respectively, assuming all the land appropriate for solar projects are developed for central PV. This large difference is caused by the inclusion or exclusion of those lands with a slope between 1% and 3%, and the fixed sandy land, semi-fixed sandy land and Gobi desert land (Table 2). The difference shows the spatial and temporal characteristics of solar resources are key to understand the availability and integration of variable solar resources.

3.2. Spatial variation of provincial solar availability

The solar resources potential varies cross provinces in China. Provinces with large solar potential capacity are most located in northwestern China for stationary solar and spread in the city clusters for distributed solar.

For central PV, Xinjiang has the largest potential capacity, close to 1400 GW, followed by Inner Mongolia, Gansu, and Jilin in the lower case. Qinghai and Shaanxi would move up in the list in the upper case if the desert land and higher elevation land can be used for solar development.

In the lower case, Xinjiang, West Inner Mongolia, East Inner Mongolia, Gansu, Jilin, Guangxi, Heilongjiang, Guangdong, and Shandong each has a potential capacity more than 100 GW. West Inner Mongolia has a potential capacity of 860 GW, combined with 540 GW in East Inner Mongolia, together make Inner Mongolia the province with the largest solar potential capacity. In the upper case, only Hubei, Anhui, Beijing, Xizang, Hunan, Chongqing, Jiangsu, Tianjin and Shanghai are with a capacity less than 100 GW, Xinjiang, Inner Mongolia, Gansu, Qinghai, and Shaanxi each has a potential capacity larger than 1000 GW. This shows solar resource are vastly available in China, however, the spatial variation across China and the concentration in northwest China are important geographical features of the solar resources.

Potential solar output has similar geographic pattern, the provinces which have large CFs also have large available land. Xinjiang, Inner Mongolia and Gansu are the top provinces, which have the potential annual output larger than 500 TWh in the lower case. In the upper case, Xinjiang, Inner Mongolia, Gansu, Qinghai, Shaanxi, Yunnan, Shanxi, Guangxi, and Guangdong have the potential annual output larger than 1000 TWh. Inner Mongolia, Xinjiang, and Gansu are the top potential producers, together accounting for 67% and 75% of national total central PV solar potential output in the lower and upper case, respectively.

For distributed solar, Table 3 shows potential capacity at provincial level varies at great scale, from about 0.3 GW in Xizang to near 14 GW in Guangdong for residential PV, and from 0.2 GW to 10 GW for commercial PV. This mainly due to the availability of rooftop space within the built-up area of cites in those provinces.

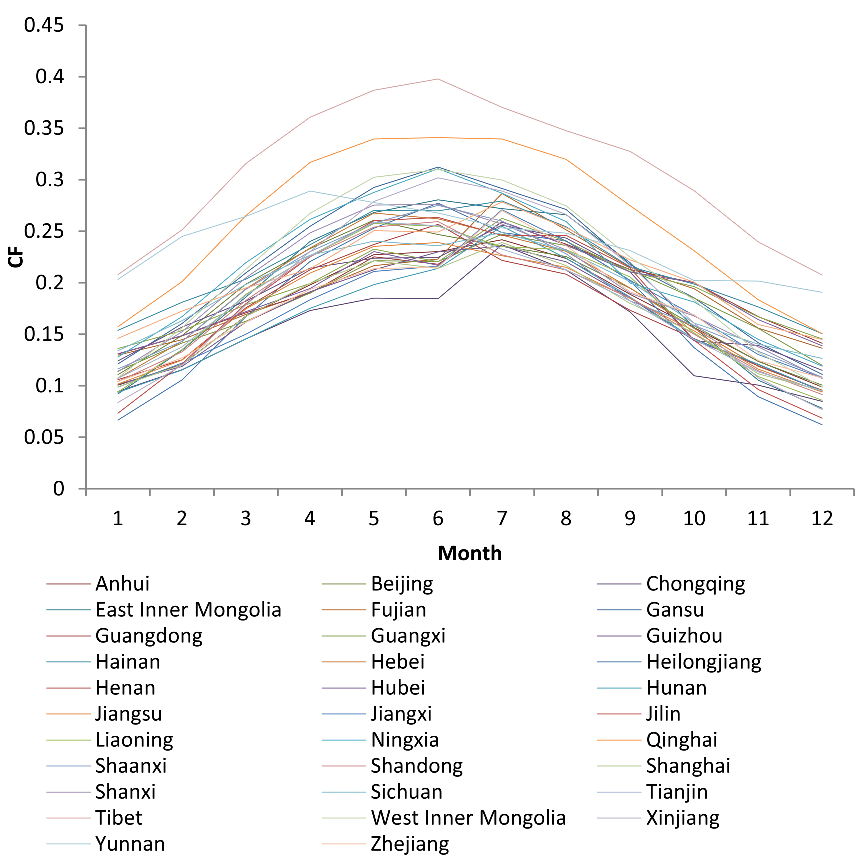

Fig. 3. Monthly average central PV capacity factor 2001–2010.

3.3. Temporal variation of provincial solar availability

CF is a good indicator to show the solar variation and its availability. We examined the hourly solar variability within a day, the daily solar variability within a month, and the monthly solar variability within a year for all the 200 chosen locations by province. Both solar and wind are temporal variable resources, however, compared to wind, the variation of solar follow the natural cycle of solar irradiation therefore is more predictable. The daily variability are extremely disperse and does not show any regular trend, however, all technologies show regular monthly (seasonal) and hourly variation pattern, due to the hourly and seasonal variation pattern of solar irradiation (Fig. 3 and Fig. 4).

Using central PV as an example, all provinces have better availability during summer than in spring, autumn and winter. CFs usually peak in June or July. The highest monthly CF reaches as high as 0.3978 in Xizang in June, and the lowest is 0.0621 in Jilin in December. The difference between the highest and the lowest month of the same province can be as high as 0.225 in Xinjiang. The highest monthly average CF is in Xizang, which is about twice the lowest average in Chongqing. Yunnan has the minimum differences between extreme values. Other technologies follow similar pattern.

For the average hourly variation within a day, the CFs peak between 12PM and 15PM, as Chinese provinces all use China Standard Time but are actually cross wide longitude. The regional differences and temporal variability of solar resources show national coordination is needed to develop transmission corridors to transmit solar power out of the solar generation areas and coordinating the time of generation and demand. The integration and optimization of solar and other complimentary resources, such as solar and wind, solar and storage, solar and hydro, other flexible sources, and demand response/demand side management will be essential to deal with such temporal variation pattern.

3.4. Potential contribution of solar generation

Similar to the wind assessment, we compared the provincial potential solar power output with projected provincial electricity demand of 2030 and showed the potential share of solar power in total electricity demand in each province. We use electricity demand of 2030 as it is the best available year with projected provincial electricity demand reported by the Electricity Supply and Demand Laboratory in the State Grid Energy Research Institute [21]. Many uncertain factors may impact the solar energy development and the total energy demand in each province, for example, economic development and industrial structure, urbanization, competition and integration from other sources, investments and costs, etc. The potential/demand ratio of solar in total energy demand is therefore an indicative number to show the potential contribution of solar can possibly achieve.

Seen from Table 4, potential/demand ratio at provincial level varies at great scale, from 0.03 of demand to more than 100 times of demand. In the lower case, West Inner Mongolia, Xinjiang, East Inner Mongolia, Gansu, Hainan, Jilin, and Heilongjiang could each produce more than its demand. Inner Mongolia in the upper case could generate more than 100 times of the projected demand which makes it the heart for solar energy. Xizang and Qinghai have relatively high average CFs but unmatched output as most of the land at high elevation, greater than 3000 m, are excluded in the assessment. Nationwide, annual potential solar output could reach

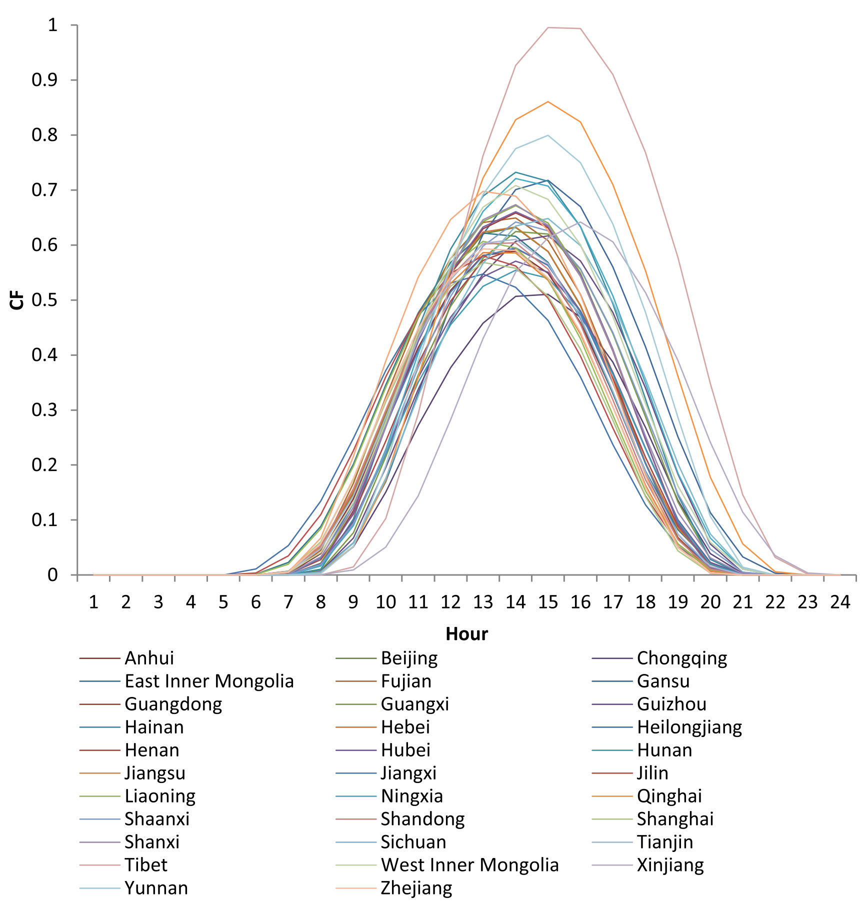

Fig. 4. Hourly average central PV capacity factor 2001–2010.

Table 4
Average capacity factor, potential solar capacity and output by province.

Province	Stationary solar										Distributed solar					
	Central PV					CSP					Residential PV			Commercial PV		
	Avg. CF	Lower case		Upper case		Avg. CF	Lower case		Upper case		Avg. CF	GW	TWh	Avg. CF	GW	TWh
		GW	TWh	GW	TWh		GW	TWh	GW	TWh						
Anhui	0.1734	8	12	34	52	0.1202	7	7	28	30	0.1290	4.5	5	0.1340	3.4	4
Beijing	0.1865	4	7	25	40	0.1855	4	6	21	34	0.1642	3.7	5	0.1711	2.7	4
Chongqing	0.1514	5	6	15	20	0.0805	4	3	13	9	0.1094	2.6	3	0.1138	2.0	2
East Inner Mongolia	0.1918	540	907	4111	6909	0.1996	450	786	3426	5990	0.1744	1.3	2	0.1816	1.0	2
Fujian	0.1931	32	55	280	473	0.1223	27	29	233	250	0.1306	3.2	4	0.1358	2.4	3
Gansu	0.2143	287	540	3692	6931	0.2253	240	473	3077	6073	0.1787	1.9	3	0.1864	1.4	2
Guangdong	0.1920	163	274	643	1081	0.1088	136	129	535	510	0.1308	13.9	16	0.1363	10.4	12
Guangxi	0.1841	199	320	707	1141	0.1037	166	150	590	536	0.1256	2.8	3	0.1310	2.1	2
Guizhou	0.1862	45	73	338	551	0.1169	37	38	282	288	0.1363	1.4	2	0.1419	1.0	1
Hainan	0.2160	91	172	205	388	0.1510	76	100	171	226	0.1452	0.7	1	0.1511	0.5	1
Hebei	0.1877	63	104	483	794	0.1850	53	85	402	652	0.1610	4.9	7	0.1677	3.6	5
Heilongjiang	0.1727	183	276	279	423	0.1562	152	208	233	319	0.1580	4.9	7	0.1639	3.7	5
Henan	0.1732	11	16	116	175	0.1241	9	10	96	105	0.1329	6.0	7	0.1380	4.5	5
Hubei	0.1682	10	15	70	104	0.1022	9	8	59	52	0.1195	5.1	5	0.1245	3.8	4
Hunan	0.1642	1	2	16	23	0.0942	1	1	13	11	0.1152	4.0	4	0.1197	3.0	3
Jiangsu	0.1730	7	11	8	12	0.1322	6	7	7	8	0.1341	9.8	12	0.1392	7.4	9
Jiangxi	0.1754	56	86	265	406	0.1128	47	46	220	218	0.1217	2.8	3	0.1266	2.1	2
Jilin	0.1784	252	393	465	727	0.1515	210	278	387	514	0.1564	3.7	5	0.1621	2.8	4
Liaoning	0.1814	59	94	420	667	0.1621	49	70	350	497	0.1559	6.7	9	0.1618	5.0	7
Ningxia	0.2140	58	108	516	968	0.2197	48	92	430	828	0.1786	1.0	2	0.1859	0.8	1
Qinghai	0.2603	30	67	1791	4082	0.2933	25	63	1492	3834	0.2157	0.3	1	0.2261	0.3	1
Shaanxi	0.1908	91	153	1106	1849	0.1636	76	109	922	1321	0.1497	2.3	3	0.1564	1.7	2
Shandong	0.1784	113	177	313	490	0.1540	94	127	261	352	0.1456	10.7	14	0.1511	8.0	11
Shanghai	0.1682	0.6	0.9	1.1	1.6	0.1251	0.5	0.6	0.9	1.0	0.1308	3.0	3	0.1356	2.2	3
Shanxi	0.1970	51	88	689	1190	0.1998	43	74	574	1006	0.1663	2.6	4	0.1733	1.9	3
Sichuan	0.1924	3	6	116	195	0.1358	3	3	97	115	0.1383	4.9	6	0.1447	3.7	5
Tianjin	0.1797	3	5	7	11	0.1672	3	4	6	8	0.1513	2.1	3	0.1577	1.5	2
Tibet (Xizang)	0.3087	1	3	21	57	0.3689	1	3	18	57	0.2379	0.3	1	0.2495	0.2	0
West Inner Mongolia	0.2144	858	1611	9488	17824	0.2463	715	1542	7907	17058	0.1901	1.8	3	0.1980	1.4	2
Xinjiang	0.1928	1363	2302	12343	20850	0.2085	1136	2074	10286	18788	0.1605	2.5	4	0.1674	1.9	3
Yunnan	0.2394	67	140	598	1253	0.2094	56	102	498	913	0.1733	2.3	3	0.1813	1.7	3
Zhejiang	0.1764	13	21	120	185	0.1238	11	12	100	108	0.1264	6.4	7	0.1314	4.8	6
Average/Total	0.1940	4700	8000	39300	69900	0.1932	3900	6600	32700	60700	0.1427	120	150	0.1522	90	120

Note: Stationary solar, central PV and CSP, compete land use, therefore only one type of technology is built at one time. Residential PV and commercial PV are supplemental in roof space.

6900 TWh and 70100 TWh in the lower case and upper case, respectively (Table 5). The potential output at national scale shows China has more than enough solar resource, and the real challenges are cost reduction, investment need, and system integration.

3.5. Sensitivity analysis and uncertainties

We conducted sensitivity analysis on several key assumptions of the GIS model and land filter: the 160 W/m^2 GHI threshold, the 1% slope threshold, the 3000-m elevation threshold. We studied the relations between those factors and the potential capacity, and plotted them in Fig. 5. The results in the upper case and lower case are quite similar as the change patterns of those factors are the same.

Those factors follow non-linear relations with the potential capacity. The potential capacity is most sensitive to the 160 W/m^2 GHI threshold. However, as 80% of the land grids have a GHI larger than 160 W/m^2, the results have already included those available resources. The results are less sensitive to the 3000-m elevation threshold. The 1% slope threshold has big impact on the final results. About 40% of China's total land cover is under 1% slope threshold. 3% slope threshold would increase to 60% of the total land cover.

In addition, there are many uncertainties that will impact the results of this study. The annual variations in some sites are not trivial, and should be incorporated into long-term assessment. The land conversion factor of different technologies, the rooftop availability in the residential and commercial land use deserve deep investigation so to make more accurate estimates. China is still in the midst of fast urbanization, more rooftop space will be available as the cities expand. Technology advancement is an active area to observe, if it enables building solar plants in more severe conditions that are not appropriate for solar development traditionally, or if the efficiency improvement would change the CF simulation, the results of this analysis will need update in the future as technologies develop.

4. Conclusion and discussion

China has released ambitious solar energy development goals. Knowing where, when and how much solar is available at provincial level can help the researchers and policy makers on solar development planning and integration. However, the existing literature does not provide the necessary spatial resolution or give sufficient attention on the spatial and temporal variation of solar availability.

In this study, combining GIS modeling and solar CF simulation with SAM model, we utilized 10-year hourly solar irradiation data from 2001 to 2011 from 200 representative locations to study provincial solar resources potential, and to build provincial solar availability profiles. We found that China could have a potential stationary solar capacity from 4700 GW to 39300 GW, distributed solar about 200 GW, and the annual solar output could reach 6900 TWh to 70100 TWh.

Table 5
Potential share of solar generation by province in 2030.

Province	Demand 2030 (TWh)	Lower case		Upper case	
		Potential output (TWh)	Potential/demand ratio	Potential output (TWh)	Potential/demand ratio
Anhui	240	16	0.07	61	0.25
Beijing	133	15	0.11	50	0.37
Chongqing	171	7	0.04	25	0.15
East Inner Mongolia	272	790	2.90	6912	25.37
Fujian	309	35	0.11	480	1.56
Gansu	205	478	2.33	6936	33.82
Guangdong	815	158	0.19	1109	1.36
Guangxi	254	156	0.61	1147	4.51
Guizhou	218	41	0.19	554	2.54
Hainan	47	102	2.14	389	8.22
Hebei	677	97	0.14	806	1.19
Heilongjiang	154	220	1.44	435	2.83
Henan	614	22	0.04	188	0.31
Hubei	342	17	0.05	113	0.33
Hunan	299	8	0.03	30	0.10
Jiangsu	792	27	0.03	32	0.04
Jiangxi	165	52	0.31	412	2.49
Jilin	140	287	2.06	736	5.27
Liaoning	409	86	0.21	684	1.67
Ningxia	141	95	0.67	971	6.87
Qinghai	97	65	0.67	4083	42.14
Shaanxi	234	115	0.49	1854	7.94
Shandong	760	151	0.20	514	0.68
Shanghai	233	7	0.03	8	0.03
Shanxi	370	81	0.22	1196	3.23
Sichuan	367	14	0.04	206	0.56
Tianjin	137	9	0.06	16	0.12
Tibet (Xizang)	7	4	0.58	58	7.96
West Inner Mongolia	163	1547	9.46	17829	109.07
Xinjiang	244	2080	8.52	20856	85.44
Yunnan	239	108	0.45	1259	5.27
Zhejiang	597	25	0.04	198	0.33
Total/Average	9845	6900	0.70	70100	7.13

We studied the diurnal and seasonal features of the solar availability at provincial level and found similar diurnal and seasonal variation patterns cross provinces. The peaking time lag within a day and the differences cross provinces offer opportunities for coordination. The diurnal and seasonal variability of solar and wind resources demand a larger, system-level analysis of China's energy options with more careful investigation of technical and economic availabilities and the role of inter-province transmissions.

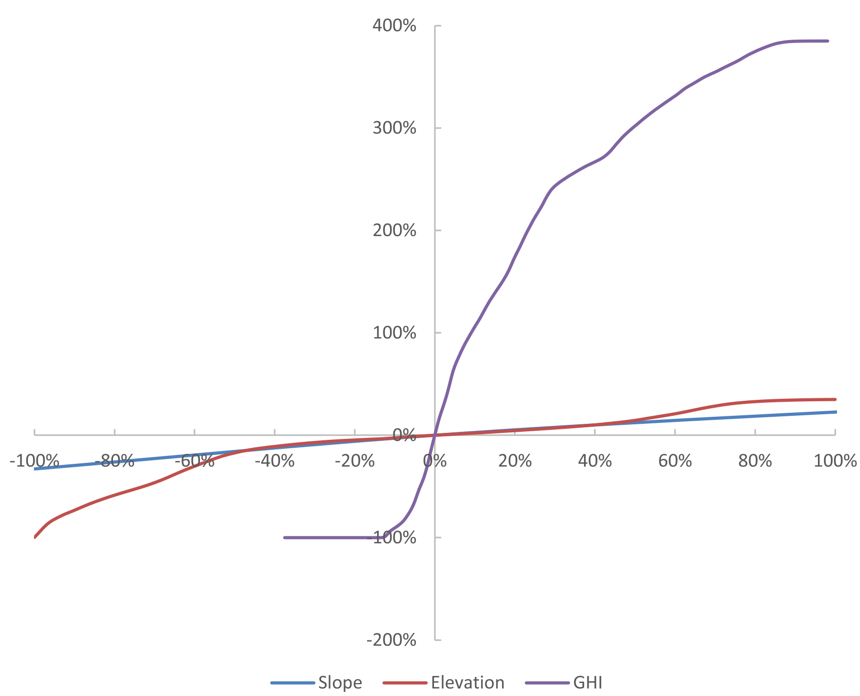

Fig. 5. The sensitivity analysis of key assumptions to the potential capacity.

Integrating variable resources, notably solar and wind, requires better understanding of where, when and how much of variable resources are available. This study fills the gap of exiting literature by investigating solar availability in China at high spatial resolution and temporal resolution so to understand the spatial and temporal availability of solar resources cross China. By adding the spatial and temporal features of China's solar resources, the results of this study can be used to facilitate local and national solar development plans and can also be utilized by developers and regulators to develop strategies on solar energy integration.

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