Supplementary Material to "Modeling the Supply of Renewable Electricity to Metropolitan Regions in China"

Table S1. Literature review of scenario analysis for the Chinese power sector.

Study	Main Findings	Modelling Approach	Sensitivity Analysis	Limitations
[1]	A carbon price of $30/tCO_2$ by 2020 is needed to meet the 2020 carbon intensity target, and the announced 2030 carbon peak can be achieved with a carbon price of $40/tCO_2$.	The SWITCH model is a linear program whose objective function is to minimize the cost of producing and delivering electricity through the construction and retirement of various power generation, storage and transmission options between present day and future target dates (over the 2050 horizon) according to projected demand. It optimizes both the long-term investment and the short-term operation of the grid. It uses a combination of existing and new grid assets. Optimization is subject to reliability, operational and resource-availability constraints, as well as both existing and possible future climate policies.	Carbon price; the limit of nuclear; the cost of CCS	Only typical daily load file is available with no difference between weekday and weekend.
[2]	The current NDCs proposed by the Chinese government of peaking emissions in 2030 are not sufficient to comply with a global CO_2 budget in line with the Paris Agreement. Given the enormous electricity demand in the population-dense coastal-east, large investments into expanding the electricity network are to be expected throughout the decarbonization process of the power sector.	Multisectoral modelling of electricity, transportation, heat and industrial sectors with a reduced hourly time-series due to memory and computation time constraints (a time-series based on each 73rd hour was chosen, resulting in 120 time periods).	A variety of different cost assumptions (e.g., storage, PV and coal); the potentials of PV and wind; projections of final energy demand; the impact of CCS; the selection of the final time-series (from every 73rd to every 25th hour).	No CSP.
[3]	Compared to a baseline design of homogeneously distributed renewable capacities, a heterogeneous network not only lowers capital investments, but also reduces backup dispatches from thermal units. By installing more capacity in provinces like Inner Mongolia, Jiangsu, Hainan and the north-western regions, heterogeneous layouts may lower the levelized cost of electricity (LCOE) by up to 27%, and reduce backup needs by up to 64%.	To compare two power system optimization designs of homogeneous allocation of wind and solar generators, in the sense that all nodes are assigned a renewable penetration of 100%, and optimizing the trade-off between low cost production and high utility value of the energy.	Solar cost reductions of 10%, 25% and 50%; interyear weather pattern variability	No CSP.

[4]	In order to achieve a reasonable transition of generation mix, it is necessary to strike a balance between exploiting energy sources in resource-rich regions and load-rich regions, promote the rapid expansion of interregional transmission grid, and valorize the role of demand side resources.	It makes decisions on the expansion of various generation sources, the expansion of transmission lines and the use of load side resources at the same time, in order to find the best development path for power systems with the minimum overall cost of the whole system.	No	Only until 2030; regional level (six regions); no CSP; no hourly operational simulation of supply-demand balance within the planning period, which means the model may fail to accurately reflect the variability and flexibility of the systems, especially when there is a certain amount of variable renewable generation.
[5]	It shows that investment decisions on coal-fired units, combined heat and power plants and renewable energy sources are significantly influenced by the choices of different targets. Reducing carbon emissions and increasing renewable energy integration generally work in tandem, but result in a higher planning cost.	In addition to the conventional economy objective, two kinds of low-carbon targets, i.e., the carbon emission target and the renewable penetration target of multiple energy sectors, are taken into account.	Carbon price; the capital cost of energy components; fuel prices	Two selected districts.
[6]	It constructs three scenarios for the reference year, 2030, where VREs account for 16%, 19% and 22% of the electricity system respectively, and simulates a corresponding residual load time series to show that the current average 1%/min ramp rate of thermal power plants is basically sufficient to deal with ramps in residual load in the future, but the current average 60% minimum load level of thermal power plants has to be improved to 40% or even 30% to reduce VRE curtailment.	It described future scenarios with 16–22% VREs in China's electricity system, and simulated corresponding residual load time series.	No	Only until 2030; no offshore wind, no CSP; no hourly modelling; no modelling of storage.
[7]	The planning of the interregional and intraregional grid development should be coordinated with the development of renewable power; and effective dispatch mechanisms which account for CO_2 emissions or generation efficiency across regions should be established. Additionally, the government plan for	The proposed power dispatch model is a unit commitment (UC) model which minimizes system costs by optimizing the power output and the commitment states of generation units while satisfying certain system constraints. The unit commitment model in this work incorporates the transmission grid, pumped	CO_2 price; electricity demand; RES penetration levels	Only until 2030; regional level (six regions); uses the data of four EU member states to represent the regional demand profiles in China; only pumped hydro is taken into consideration as a

	interregional transmission capacity in 2030 is basically sufficient to enable bulk power delivery and promote renewable generation across regions.	hydro storage and flexible demand (e.g. electric vehicle charging), which enables us to compare different flexibility providers for the power system operation.		storage technology.
[8]	It shows that renewable portfolio standards (RPS) and national carbon cap-and-trade policies contain overlapping elements, yet they will have different impacts on regional power structures, interregional power and coal dispatches. If an RPS with a 17% nonhydro renewable share is implemented by 2030, the effective interval of carbon caps will be between a 27.5% and 38.2% reduction in carbon intensity. The results support that there are strong inner linkages between reasonable power system planning and the current status of policy mix.	It quantitatively evaluates the effects of RPS and carbon caps in China's power sector using a multiregional power optimization model combined with the decomposition method.	No	Only until 2030

Table S2. Assumed market shares for modes and vehicle types under the renewable and import scenario (RIS) in study regions [9].

Market Shares Transport (RIS)	**2015**	**2020**	**2030**	**2040**	**2050**
Aviation domestic	11%	11%	8%	7%	7%
Navigation	4%	4%	4%	4%	4%
Pipeline Transport	0%	0%	0%	0%	0%
Rail	4%	5%	7%	10%	15%
Electric train etc.	*55%*	*70%*	*89%*	*96%*	*99%*
Diesel train	*45%*	*30%*	*11%*	*4%*	*1%*
Road: total (PC + LDV + HDV)	80%	80%	82%	79%	75%
PC + LDV (in total road)	*82%*	*82%*	*81%*	*80%*	*80%*
HDV (in total road)	*18%*	*18%*	*19%*	*20%*	*20%*
Road: PC + LDV					
Biofuel/Synfuel vehicle	0%	1%	4%	10%	7%
Electric vehicle	4%	4%	8%	27%	40%
Gas vehicle	3%	4%	4%	3%	1%

Gasoline/diesel car + others	93%	90%	68%	23%	2%
Hybrid vehicle	0%	1%	12%	28%	31%
Hydrogen car	0%	0%	3%	9%	18%
Road: HDV					
Biofuel/Synfuel vehicle	0%	1%	5%	18%	31%
Electric vehicle	0%	0%	7%	21%	30%
Gas vehicle	2%	2%	3%	3%	1%
Gasoline/diesel car + others	98%	97%	81%	43%	8%
Hybrid vehicle	0%	0%	1%	7%	16%
Hydrogen car	0%	0%	3%	8%	15%

Table S3. Exogenous capacities of renewable and fossil fuel power plants in the study regions. Exogenous input data on capacities of renewable power generation in the study regions by scenario year.

	Technology	**Onshore wind**	**Offshore wind**	**PV**	**CSP**	**Biomass**	**Geothermal**
Year	**Life time**	**25 yrs**	**25 yrs**	**25 yrs**	**40 yrs**	**25 yrs**	**20 yrs**
	Unit	GW	GW	GW	GW	MW	MW
2020	Beijing	0.5	-	1	-	109	0
	Tianjin	1	0.1	0.8	-	83	10
	Hebei	18	0.5	12	1	1640	10
	Inner Mongolia	45	-	12	3	340	0
2030	Beijing	0.5	0	1	-	109	0
	Tianjin	1	0.1	0.8	-	83	10
	Hebei	18	0.5	12	1	1640	10
	Inner Mongolia	45	-	12	16	340	0
2040	Beijing	0.3	0	1	-	0	0
	Tianjin	0.9	0.1	0.8	-	0	0
	Hebei	13	0.5	12	1	1202	0
	Inner Mongolia	31	-	12	16	174	0
2050	Beijing	0	0	0	-	0	0
	Tianjin	0	0	0	-	0	0
	Hebei	0	0	0	1	0	0
	Inner Mongolia	0	-	0	7	0	0

Table S4. Base year 2015 and exogenous input data on capacities of fossil fuel power plants in the study regions by scenario year.

	Technology	**CCGT**	**GT**	**Coal**	**Lignite**
Year	**Life time**	**30 yrs**	**30 yrs**	**40 yrs**	**40 yrs**
	Unit	GW	GW	GW	GW
2015	Beijing	1.5	0.01	1.6	0
	Tianjin	0.06	0	10.7	0.6
	Hebei	0.2	0	32.5	1.6
	Inner Mongolia	0.7	0	35.6	20.1
2020	Beijing	8.3	0.01	1.6	0
	Tianjin	2.7	0.12	10.8	1.3
	Hebei	0.3	0.17	41.5	2.8
	Inner Mongolia	1.2	0	41.8	25.8
2030	Beijing	8.3	0.01	1.0	0
	Tianjin	2.7	0.12	10.4	1.3
	Hebei	0.3	0.17	38.8	2.4
	Inner Mongolia	1.2	0	43.0	24.3
2040	Beijing	6.8	0	0	0
	Tianjin	2.7	0.12	7.4	1.3
	Hebei	0.02	0.17	31.1	2.0
	Inner Mongolia	0.5	0	40.1	22.3
2050	Beijing	0	0	0	0
	Tianjin	0	0	0.2	0.7
	Hebei	0	0	10.2	1.2
	Inner Mongolia	0	0	7.6	6.0

1. Assessment of Renewable Energy Resource Potentials in China

1.1. Introduction

In light of the imbalanced distribution of human activities and resources in China, the assessment of renewable energy resource potential is a prerequisite for evaluating how its deployment could support the decarbonization of China's energy sector. We therefore conducted a nationwide RE potential assessment of the power generation of onshore and offshore wind, PV and CSP with provincial-/municipal-level resolution. The results for the study regions are presented here. In addition, the renewable energy potentials of biomass, geothermal, small hydro and pumped hydro power were evaluated based on a literature review.

1.2. Methodology and Data

The renewable energy resource potentials of wind and solar for power generation in China were assessed by applying the Energy Data Analysis Tool (EnDAT), developed by [10] and expanded by [11]. It performs a land use assessment to identify areas in which the wind and solar resources can be exploited, and is then overlapped with meteorological weather data and typical technology data such as power curves. The Global Land Cover database at a spatial resolution of 300 m x 300 m with 23 land use types is employed to identify suitable areas for power generation from renewables with three categories, i.e., closed to open (>15%) shrub land, closed to open (>15%) herbaceous and sparse (<15%) vegetation and bare areas in each pixel of 0.045°, being taken into consideration [11]. The minimum distance away from settlement is set to 1 km. According to the geographical conditions of China, the maximum elevation could reach 3000 m or even 3500 m [12] for renewable resource-abundant regions (such as Qinghai Province) [13]. In the assessment of the Chinese provinces, the default values in EnDAT were therefore changed, e.g., for the maximum elevation and for the minimum annual Direct Normal Irradiance (DNI) for the economic deployment of CSP. Maximum elevation was set to 3000 m instead of the default value of 2500 m. as large plains with good insolation are located at high elevation. A summary of the main exclusion criteria to determine suitable areas for the installation of solar and wind power plants in China is shown in **Error! Reference source not found.**S5.

Table S5. Main exclusion criteria to determine suitable areas for the installation of solar and wind power plants in China.

Renewable Energy	Solar		Wind	
Technology	**Open area PV**	**CSP**	**Onshore**	**Offshore**
Minimum resource	/	1600 kWh/yr	4 m/s	5 m/s
Maximum slope [°]	45	2.1	15	15
Maximum elevation above sea level [km]	3	3	3	/
Minimum distance to settlement [km]	1	1	1	/
Maximum distance from coast within exclusive economic zones (EEZ) [km]	/	/	/	200
Maximum sea depth [m]	/	/	/	40

The potentials analysis and the generation of hourly time series for PV, CSP and onshore and offshore wind were generated with EnDAT, based on the NASA SSE 6.0 dataset for 1984 to 2004, which has an hourly temporal resolution and 0.045° spatial resolution. The hourly power generation is based on bottom-up power plant models in terms of installable capacity, technology parameters and resource availability for different scenario years with consideration of assumed technological improvements (see Error! Reference source not found.S6). From the time series, a pixel-based, typical meteorological year is generated to determine the most representative month out of the long-term data available, with a better representation of variable solar irradiance and wind speed [11]. Following this resource and land use assessment, EnDAT calculates the maximum installable capacities on the suitable areas and their potential power output. For PV, the area-specific installable capacity is derived at the standard testing conditions from module efficiency and q-factor representing the efficiency of the remaining plant components, such as DC–AC converters [11]. The hourly electricity output of each grid is determined by the parameters of hourly average irradiance on the PV module, both from satellite data of global horizontal irradiance (GHI), and beam normal irradiance (BNI) and the loss factor of PV modules accounting for shadowing and dirt. Other influencing factors are the hourly average difference of the module temperature and the temperature at standard testing conditions (25 °C) multiplied by the temperature factor representing the temperature dependence of the module's performance. In addition, an availability factor is taken into account with consideration of the module breaking down or maintenance periods [11]. Both centralized and decentralized PV power plants are taken into consideration.

For CSP solar fields, a defined nameplate capacity is considered: at a standard irradiance of 800 W/m^2, a solar field with a nameplate capacity of 1 MW generates a thermal power output of 1 MW. At higher irradiances, the thermal power output can thus be higher than the nameplate capacity of the solar field. The default technology is a parabolic trough system with an area-specific installable solar field capacity of 176.2 MW$_{th}$/km^2. To calculate the potential hourly output for each raster cell, the direct irradiance on the tilted surface of the parabolic troughs is calculated from the DNI, then related to the standard DNI of 800 W/m^2, and finally, multiplied with the installable capacity. The lower threshold for the annual direct normal irradiance sum was set to 1600 kWh/m^2/yr. This is lower than the threshold of 1800 or 2000 kWh/m^2/yr in previous global ([14]), country specific ([15,16]) or regional ([17]) assessments with consideration of local resources and economic constraints. The reason for using a lower threshold is the assumption that the distance to load centers might play a significant role in China, and might compensate for lower resource quality due to reduced transmission costs. Now, there is one CSP demonstration project located in Hebei Province (see Figure S3, No. 9) with a local DNI value of 1600 kWh/m^2/yr, which is close to a load center compared to provinces with higher DNI resources in northwestern China, which are far from consumption centers in eastern China. With consideration of the technological requirements of CSP, the maximum slope is defined as 2.1 [11].

For the installation of wind turbines, the minimum distance is guaranteed to minimize the influence of interference. The area-specific installable capacity is calculated by the nominal capacity of a single wind turbine over its area demand determined by the parameters of distance factor and turbine diameter. The corresponding wind electricity is determined by the maximum installable capacity and the velocity of wind at the assumed turbine hub height [11]. The threshold of wind speed for minimum power generation is 4 m/s for onshore wind and 5 m/s for offshore wind. Then, the results of the maximum installable capacities for each form of technology in each grid are aggregated on a provincial level based on the geographical boundary data from [18].

Table S6. Parameters for calculating installable capacities and power output according to [11].

Parameter	**2010**	**2020**	**2030**	**2040**	**2050**
PV module efficiency [%]	16.1	17.3	18	18	18
PV q-factor [%]	81.1	82	82.9	83.8	84.7
Loss factor of centralized PV [%]	10	10	10	10	10
Loss factor of decentralized PV [%]	15	15	15	15	15
Temperature coefficient PV [1/°C]	−0.005	−0.0045	−0.0045	−0.004	−0.004
CSP thermal capacity factor [MW_{th}/km]	176.2	176.2	176.2	176.2	176.2
Availability factor of CSP [%]	0.95	0.95	0.95	0.95	0.95
Efficiency of the CSP power block [%]	0.37	0.37	0.37	0.37	0.37
Efficiency of the CSP thermal storage [%]	0.95	0.95	0.95	0.95	0.95
Onshore wind nominal capacity turbine [kW]	1950	3400	4400	5000	5500
Offshore wind nominal capacity turbine [kW]	3000	6000	8000	10,000	12,000
Onshore wind rotor diameter [m]	77.5	102.3	116.4	124.1	130.1
Offshore wind rotor diameter [m]	96.1	135.9	156.9	175.4	192.2
Onshore and offshore wind distance factor [m]	6	6	6	6	6
Hub height for onshore wind turbines [m]	112	122	127	131	132
Hub height for offshore wind turbines [m]	80	102	116	128	140
Loss factor wind [%]	0.15	0.15	0.15	0.15	0.15
Availability factor wind [%]	0.95	0.95	0.95	0.95	0.95
Input data	**2010**	**2020**	**2030**	**2040**	**2050**
PV area-specific installable capacity [MW/km^2]	130.6	141.9	149.2	150.8	152.5
CSP solar field area-specific installable capacity [MW_{th}/km^2]	176.2	176.2	176.2	176.2	176.2
Onshore wind area-specific installable capacity [MW/km^2]	10.4	10.4	10.4	10.4	10.4
Offshore wind area-specific installable capacity [MW/km^2]	10.4	10.4	10.4	10.4	10.4

The annual biomass energy potential in chemical TWh is calculated from provincial biomass power potentials with assumed full load hours of 5844 and power plants efficiency of 0.3 [19]. The annual geothermal exploitable energy could reach 37.8 TWh nationally [20]. Medium to low geothermal potentials can be found in the Beijing-Tianjin-Hebei region (6.1 TWh). The pumped hydro storage potential in China is 200 GW [21]. The planned pumped hydro power stations will reach 60 GW during the period from 2016 to 2020, with a total installed target of 40 GW by 2020 [22]. Since the distribution of the 200 GW potential is unknown, the distribution of the planned stations given in [22] is used as a proxy to distribute the total potential. Apart from that, the explored coastal sea water pumped storage potentials in eight provinces from near-shore and islands is 42 GW [23]; this could make the development of storage in large offshore wind bases in, e.g., Zhejiang and Jiangsu Province, economically feasible.

1.3. Results

1.3.1. Wind Energy

The results for wind power generation potential show that the onshore wind potential is concentrated in north-western China because of better wind speeds and useable land resources (see **Error! Reference source not found.**). All coastal regions have potential for offshore wind power capacity of between 6–9 MW/km^2.

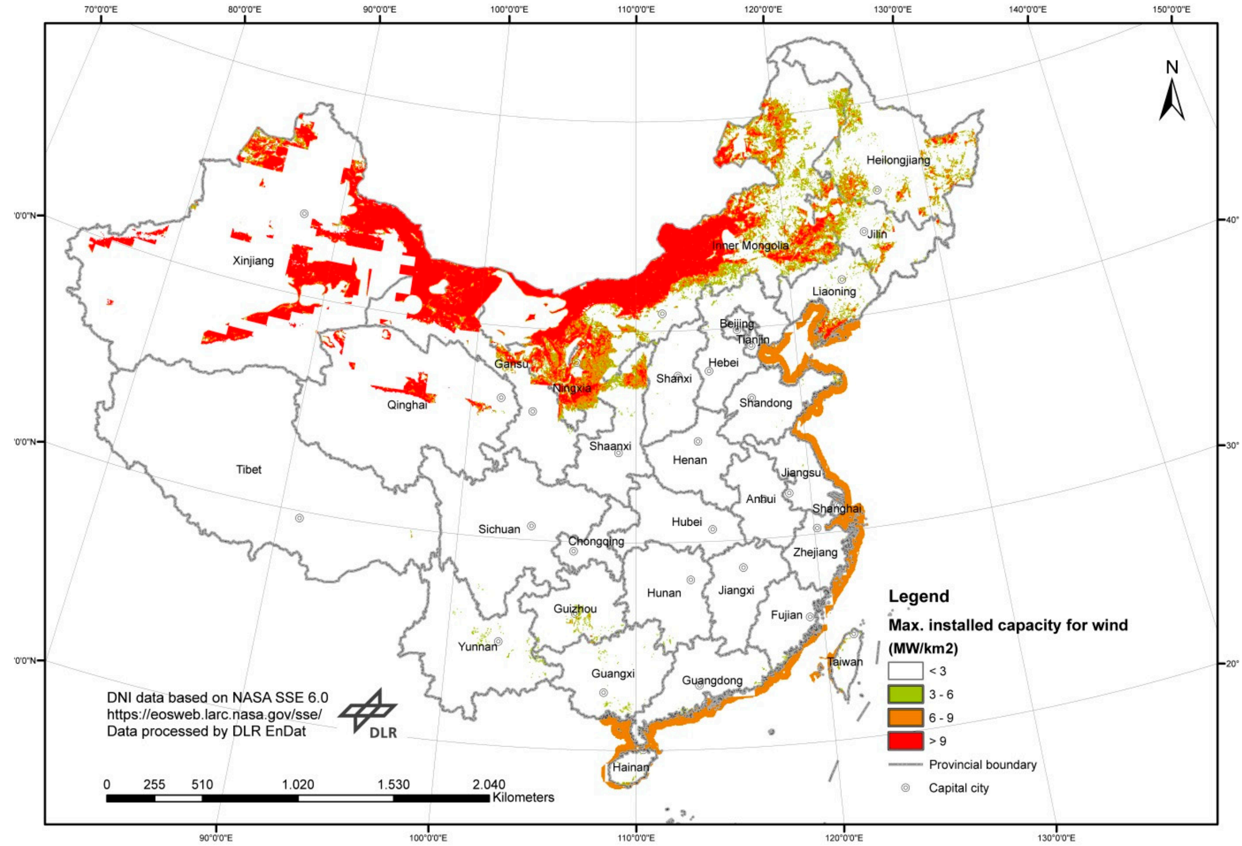

Figure S1. Maximum installable wind power capacity per km² over 4 m/s threshold in China.

The annual power generation potential in terms of maximum installable capacities and average full load hours (FLH), as well as hourly time series, were calculated with EnDAT. Four different thresholds from 4 m/s to a maximum of 6.5 m/s for onshore wind, and 7 m/s for offshore wind, were applied to evaluate capacities and corresponding FLH in the study regions (see Error! Reference source not found.S7). Since onshore wind resources in Inner Mongolia have such high potential, the highest threshold of 6.5 m/s is applied to determine the greatest economic output for its onshore wind power generation. Beijing, Tianjin, Shanghai and Jiangsu Provinces only have onshore wind potentials below 5 m/s, while Hebei, Zhejiang and Inner Mongolia also have onshore wind potentials above 6 m/s. According to the different assessment thresholds applied, the maximum installed onshore wind capacity for power generation ranges from 20 GW to 40 GW in the BTH region, and from 1700 GW to 5400 GW in Inner Mongolia as a potential supply region. The FLH increases with higher wind speed. Compared with onshore wind, the potential maximum installed offshore wind capacities in the two study regions are higher, with ranges from 80 GW to 90 GW in the BTH region.

Table S7. Onshore and offshore wind power generation potentials under different wind speed thresholds in study regions and Inner Mongolia.

	Onshore Wind							
	4 m/s		5 m/s		6 m/s		6.5 m/s	
	Max. installed capacity	FLH	Max. installed capacity	FLH	Max. installed capacity	FLH	Max. installed capacity	FLH
	GW	h	GW	h	GW	h	GW	h
Beijing	0.5	1477	0.175	2021		-		
Tianjin	2.6	1492	1.499	1573		-		
Hebei	34	2538	28.97	2752	24	2941	21	3041
BTH region	**37**	**2449**	**31**	**2690**	**31**	**2690**	**21**	**3041**
Inner Mongolia	**5382**	**2447**	**5253**	**2470**	**4598**	**2571**	**1738**	**2950**
	Offshore Wind							
	4 m/s		5 m/s		6 m/s		7 m/s	
	Max. installed capacity	FLH	Max. installed capacity	FLH	Max. installed capacity	FLH	Max. installed capacity	FLH
	GW	h	GW	h	GW	h	GW	h
Beijing				-				
Tianjin	39	1966	39	1966	11	2083		
Hebei	49	1985	41	2071	16	2202	-	
BTH region	**88**	**1976**	**88**	**1976**	**27**	**2021**		
Inner Mongolia				**-**				

1.3.2. Solar Energy

The potential of PV technology for power generation is distributed nationwide, but is still concentrated in north-western China (see Error! Reference source not found.). Three thresholds for minimum annual direct normal irradiances of 1600, 1900 and 2000 kWh/m2/yr were applied to evaluate the maximum installed CSP capacities and corresponding full load hours in the study regions. CSP generation potential exists in Hebei Province of the BTH region, but only to a small extent. However, large potential exists in the north-western provinces of Inner Mongolia, Xinjiang, Qinghai, Gansu, Ningxia, where also most of the current 20 CSP demonstration projects are located (see Error! Reference source not found.). The highest threshold of 2000 kWh/m2/yr is applied to Inner Mongolia to determine the greatest economic output for CSP power generation. Due to lower CSP resources, a threshold of 1800 kWh/m2/yr is applied to Hebei Province (see **Error! Reference source not found.**S8).

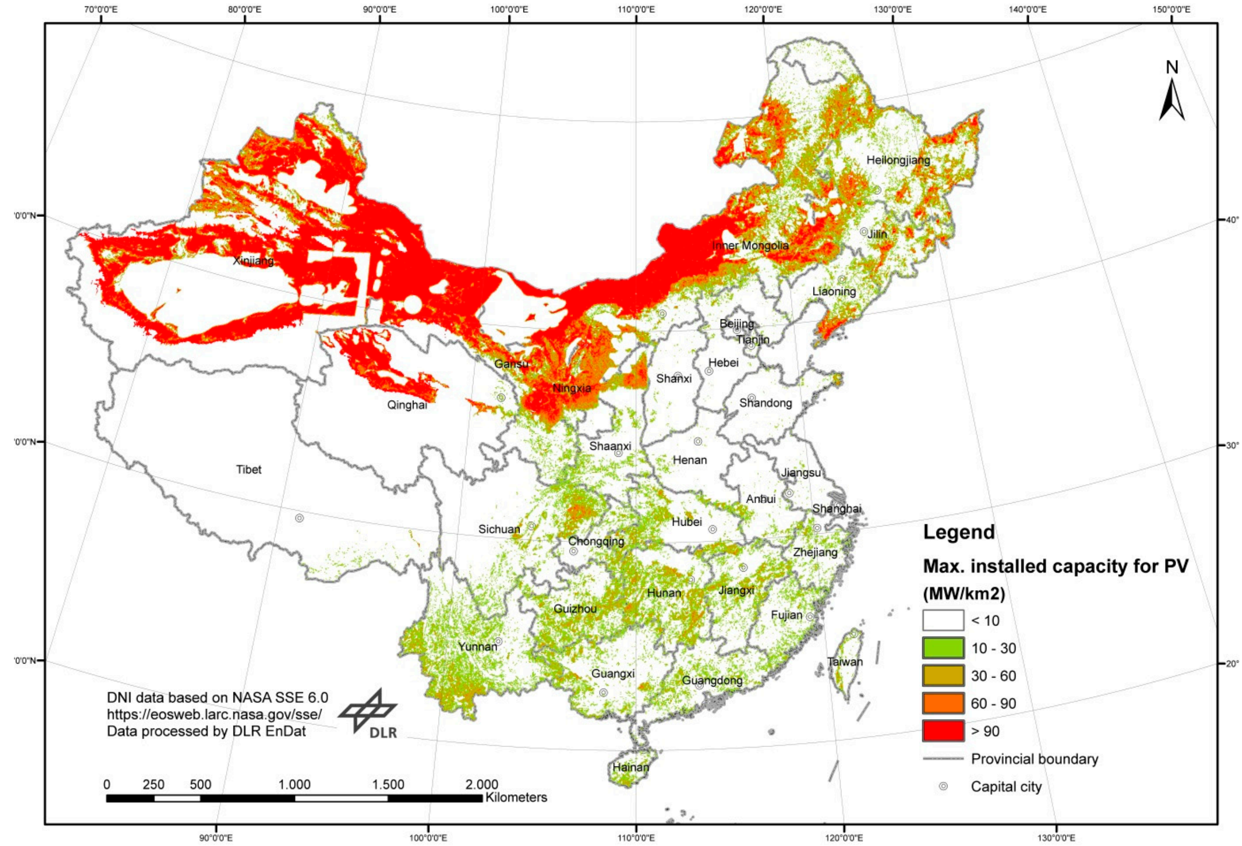

Figure S2. Maximum installable PV capacity per km² in China.

Table S8. PV and CSP potentials for power generation in the study regions and in Inner Mongolia.

	PV		**CSP**					
			1800 kWh/m²/yr		1900 kWh/m²/yr		2000 kWh/m²/yr	
	Max. installed capacity GW	FLH h	Max. installed capacity GW	FLH h	Max. installed capacity GW	FLH h	Max. installed capacity GW	FLH h
Beijing	6	1218			-			
Tianjin	25	1176			-			
Hebei	345	1256	7	1600		-		
BTH region	**376**	**1250**	**7**	**1600**		**-**		
Inner Mongolia	**53154**	**1268**	**25661**	**1664**	**9100**	**1735**	**919**	**1665**

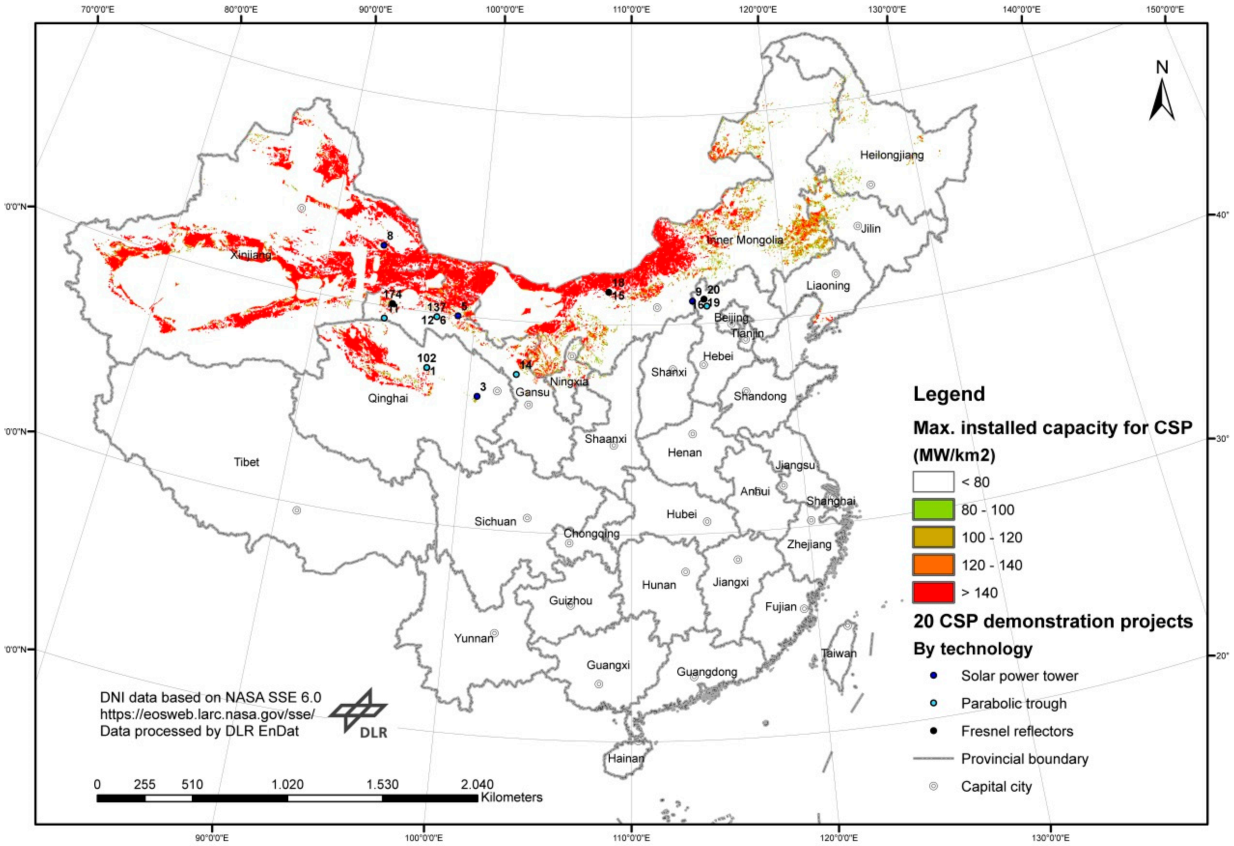

Figure S3. Maximum installable CSP capacity per km^2 and distribution of 20 demonstration CSP projects by technology in China.

1.3.3. Hydro Power

The hydro power resources in China are concentrated in the three south-western provinces, i.e., Sichuan, Yunnan and Tibet, while eastern coastal China only accounts for a very low potential (see **Error! Reference source not found.**). The hydro power generation of today corresponds very well with the exploitable potential in eastern China, whereas in the middle of China, and especially in the western part, a relatively high portion of the technical potential[1] has not yet been deployed due to environmental constraints [24].

[1] Technical potentials: geographical and technical restrictions limit the theoretical potentials (the theoretical potential of a renewable resource is the amount of the physical energy flow) [17].

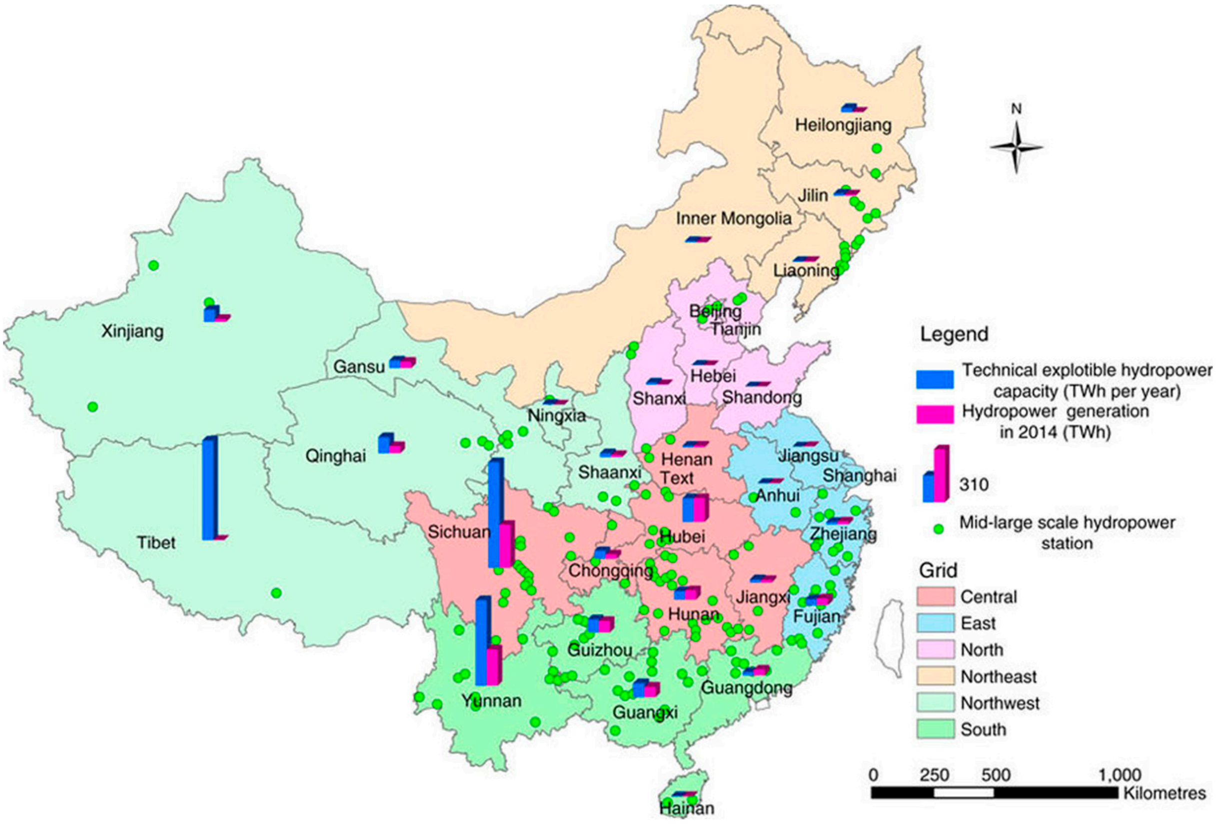

Figure S4. Spatial distribution of technical exploitable hydro power in China [25].

More specifically, according to the report of [26], the economic potential of hydro power in China is concentrated in the south-western provinces of Sichuan, Yunnan, Guizhou and Guangxi, the central provinces of Hubei and Hunan, and the north-western provinces of Xinjiang and Qinghai. The hydro power resources in the BTH region are relatively very limited (see **Error! Reference source not found.**S8).

Table S8. Hydro power potential by province in China [26].

Region/Province	Theoretical Potentials		Technical Potentials		Economic Potentials	
	Installed capacity GW	Generated electricity TWh	Installed capacity GW	Generated electricity TWh	Installed capacity GW	Generated electricity TWh
Sichuan	144	1257	120	612	103	523
Yunnan	104	914	102	492	98	471
Hubei	17	151	36	139	35	138
Guizhou	18	158	19	78	19	75
Guangxi	18	155	19	81	19	80
Xinjiang	38	334	17	71	16	68
Qinghai	22	192	23	91	15	56
Hunan	13	116	12	49	11	46
Fujian	11	94	10	35	10	35
Gansu	15	130	11	44	9	37
Tibet	201	1764	110	576	8	38
Chongqing	23	201	10	45	8	38
Heilongjiang	8	66	8	24	7	21
Zhejiang	6	54	7	16	7	16

Shaanxi	13	112	7	22	7	22
Jilin	3	30	5	12	5	12
Guangdong	6	53	5	20	5	18
Jiangxi	5	43	5	17	4	14
Shanxi	6	49	4	12	4	12
Henan	5	41	3	10	3	9
Inner Mongolia	6	51	3	7	3	7
Liaoning	2	18	2	6	2	6
Ningxia	2	18	1	6	1	6
BTH region	**2**	**20**	**2**	**4**	**1**	**3**
Anhui	3	27	1	3	1	3
Hainan	1	7	1	2	1	2
Shandong	1	10	0.1	0.2	0.1	0.1
Jiangsu and Shanghai	2	15	0.1	0.2	0.02	0.1
China	**694**	**6083**	**542**	**2474**	**402**	**1753**

1.3.4. Other Renewable Energy Resources

The other regional RE resources for power generation are summarized in **Error! Reference source not found.**S9, based on literature review. Compared to wind and solar energy, the other renewable energy resources for power generation are relatively low, in both the two study regions and in Inner Mongolia. However, pumped hydro power could act as storage to balance fluctuating wind and PV generation in the study regions and in Inner Mongolia. Biomass can have other competitive uses, e.g., as fuel for heat and transport.

Table S9. Biomass, geothermal, small hydro (5-50 MW) and pumped hydro potentials for power generation and storage in the study regions and Inner Mongolia.

	Biomass [26]		**Geothermal** [26]		**Small Hydro (5-50 MW)** [26]		**Pumped Hydro** [26]
	Max. installed capacity	FLH	Max. installed capacity	FLH	Max. installed capacity	FLH	Max. installed capacity
	GW	h	MW	h	MW	h	GW
Beijing	0.4	5844	94	6654	186	2263	2
Tianjin	0.6	5844	364	6654	5	4000	1
Hebei	8	5844	461	6654	1206	3191	12
BTH region	**9**	**5844**	**918**	**6654**	**1397**	**3071**	**15**
Inner Mongolia	**8**	**5844**	**6**	**6654**	**658**	**3236**	**12**

1.4. Summary and Discussion

The assessment of potentials shows that the eastern coastal regions of China have relatively low RE resources for power generation compared with northern and western China, in terms of solar, onshore wind and hydro. However, the abundant offshore wind in eastern coastal China could be fully exploited with the assumed cost reduction of offshore wind technology. Eliminating administrative barriers and implementing supporting storage technologies such as pumped hydro, power to hydrogen, etc. are generally seen as important preconditions. Instead of fossil fuels that are dominated by coal for power and heat supply in China, solar and wind energy could contribute significantly to the energy system transition in China. Notably, Inner Mongolia, with its abundant wind and solar energy, could act as key supply region for the eastern coastal metropolitan regions, especially the neighboring BTH region. The RE potential for power generation could also cover additional power demand from the electrification of heat and transport sectors as an important measure for decarbonization. National planning of power transmission capacity expansion largely relies on the distribution of RE resources and demand [1,27].

2. Optimization Results with Sensitivity Analysis

Continuously increasing investments would be required for installed capacities of power plants, storages and grid expansion, according to the RIS scenario. However, the total fuel costs from fossil fuel power plants would be reduced in the long term (see **Error! Reference source not found.**S5), especially considering the increase in fuel demand in the REF scenario compared with the RIS scenario (see Chapter 4). In the BTH region, fuel costs for coal power plants and natural gas for CCGT would peak during the 2020–2030 period. In contrast, fuel costs for natural gas used for gas turbines (GT) would increase each decade until 2050. In the last decade, fuel costs for coal power plants in the supply region of Inner Mongolia would decrease sharply to only 1.1 billion €, with some remaining fuel costs for natural gas used for CCGT, GT and CSP as back-up fuels, which would provide additional flexibility in wind- and PV-dominated power supply systems.

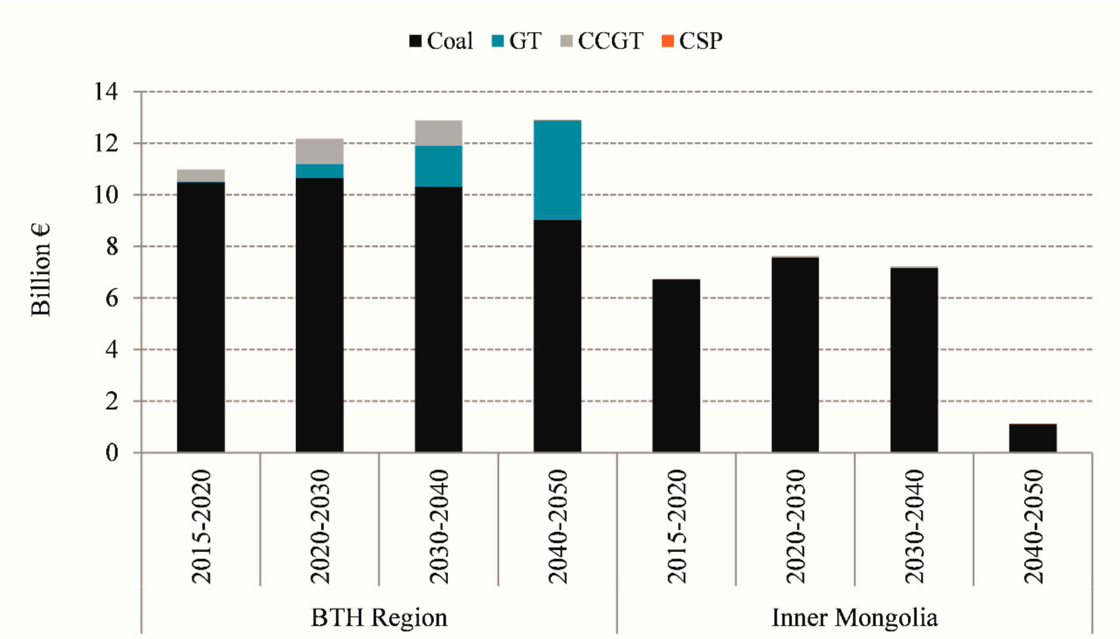

Figure S5. Fuel costs by power generation technology per decade from 2015 to 2050 in the supply and metropolitan regions under a high fuel price path.

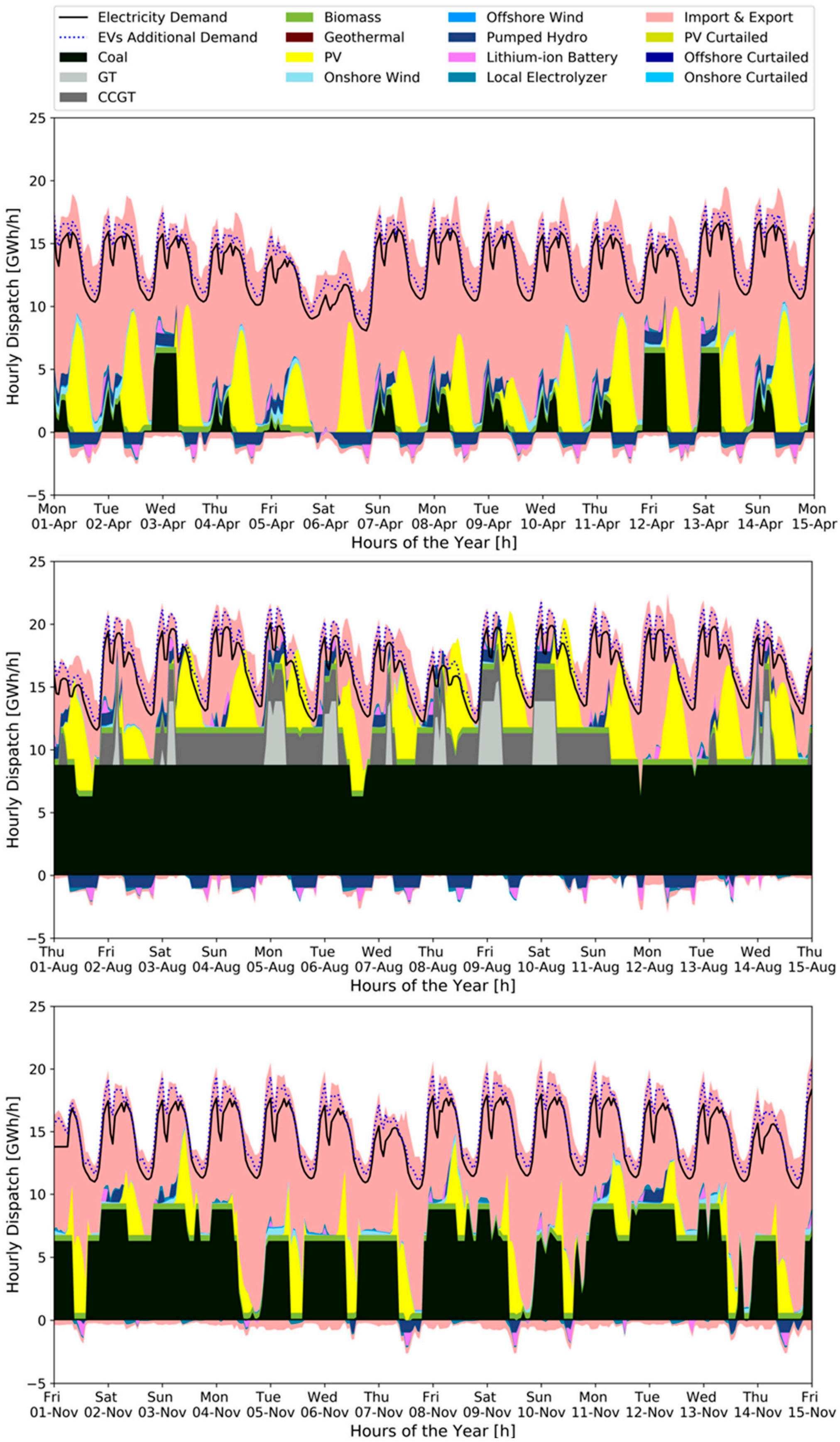

Figure S6. Typical hourly generation for each form of technology, export and charge (-), import and discharge (+) to meet power demand in Tianjin in April, August and November in 2030.

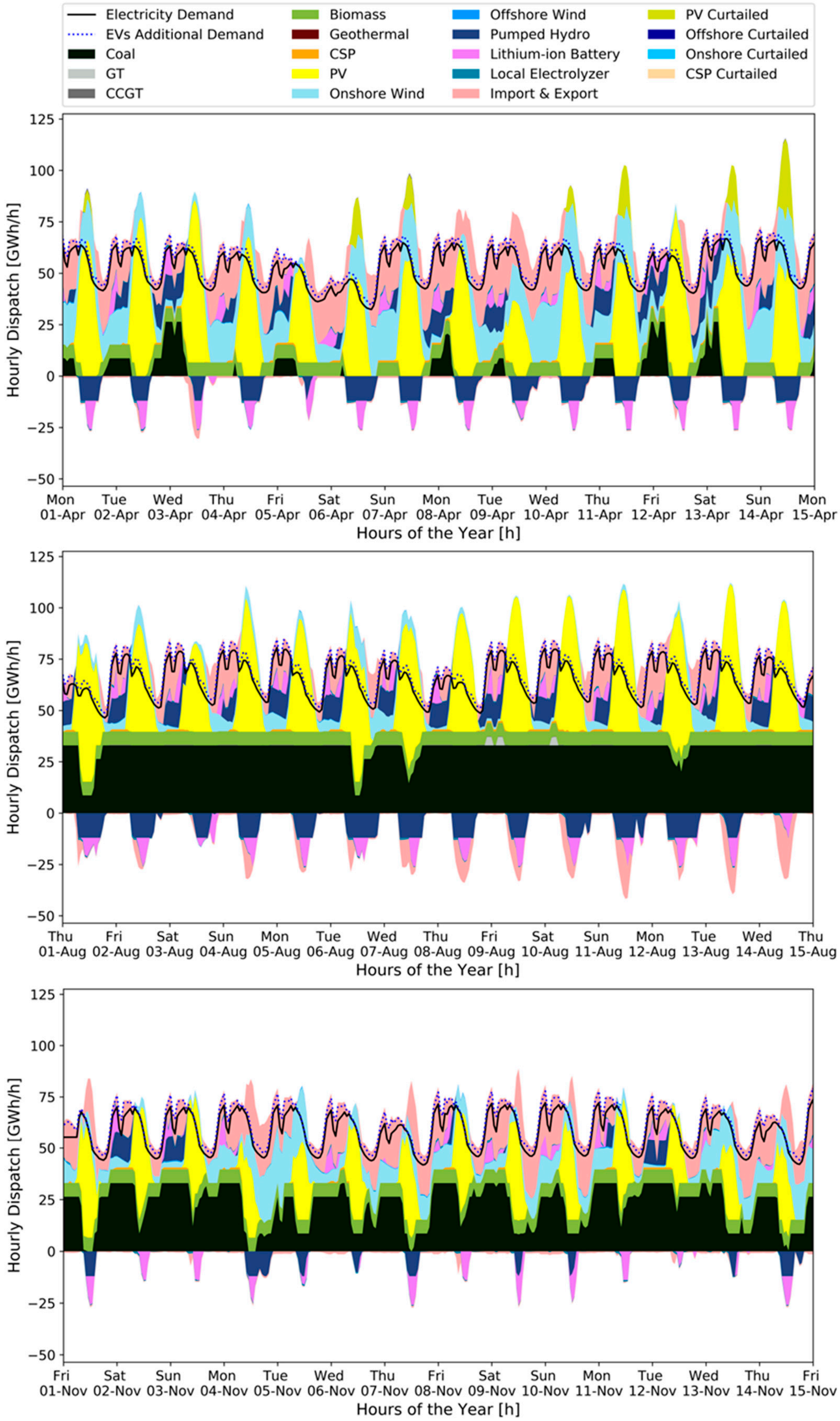

Figure S7. Typical hourly generation for each form of technology, export and charge (-), import and discharge (+) to meet power demand in Hebei in April, August and November in 2030.

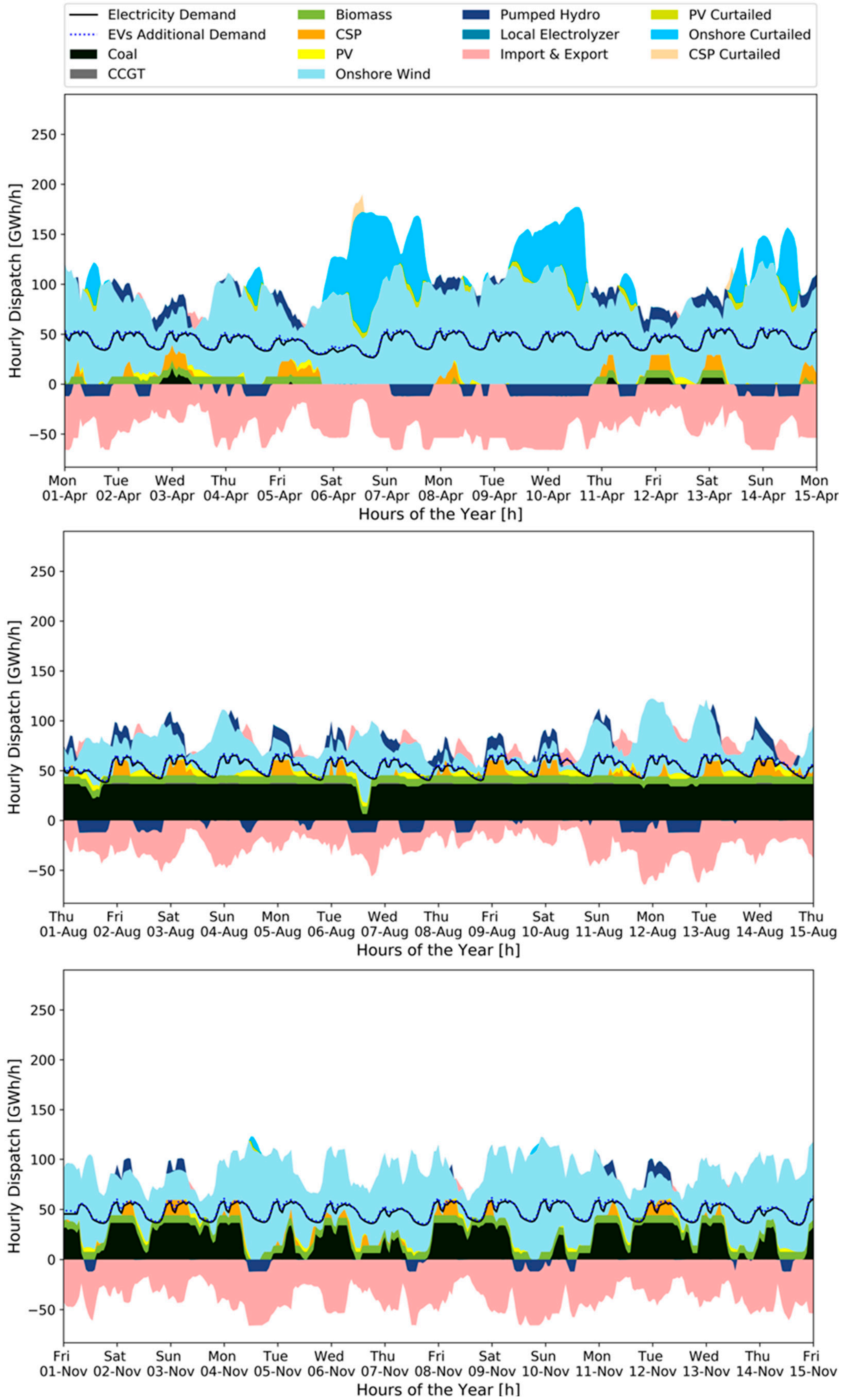

Figure S8. Typical hourly generation for each form of technology, export and charge (-), import and discharge (+) to meet power demand in Inner Mongolia in April, August and November in 2030.

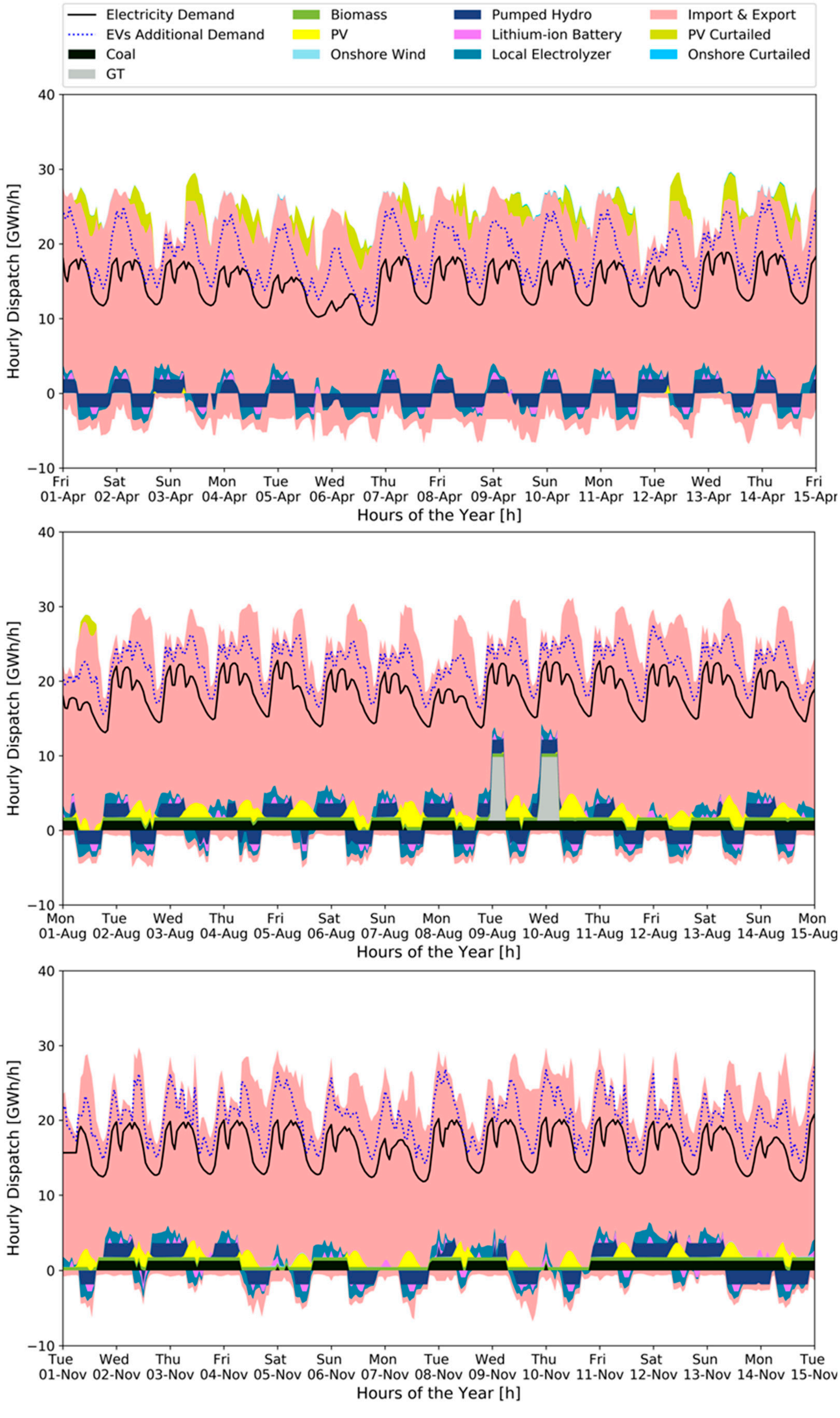

Figure S9. Typical hourly generation for each form of technology, export and charge (-), import and discharge (+) to meet power demand in Beijing in April, August and November in 2050.

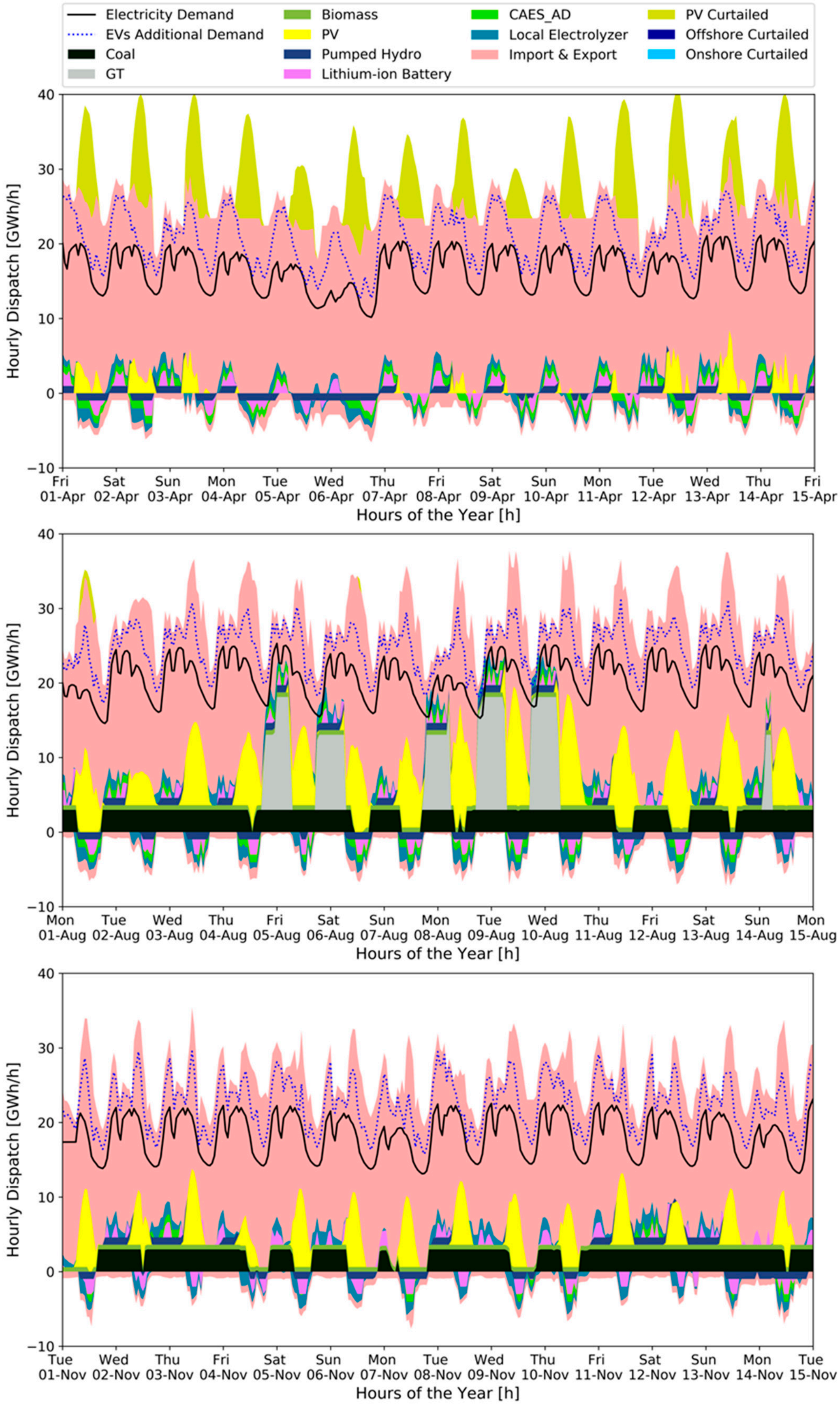

Figure S10. Typical hourly generation for each form of technology, export and charge (-), import and discharge (+) to meet power demand in Tianjin in April, August and November in 2050.

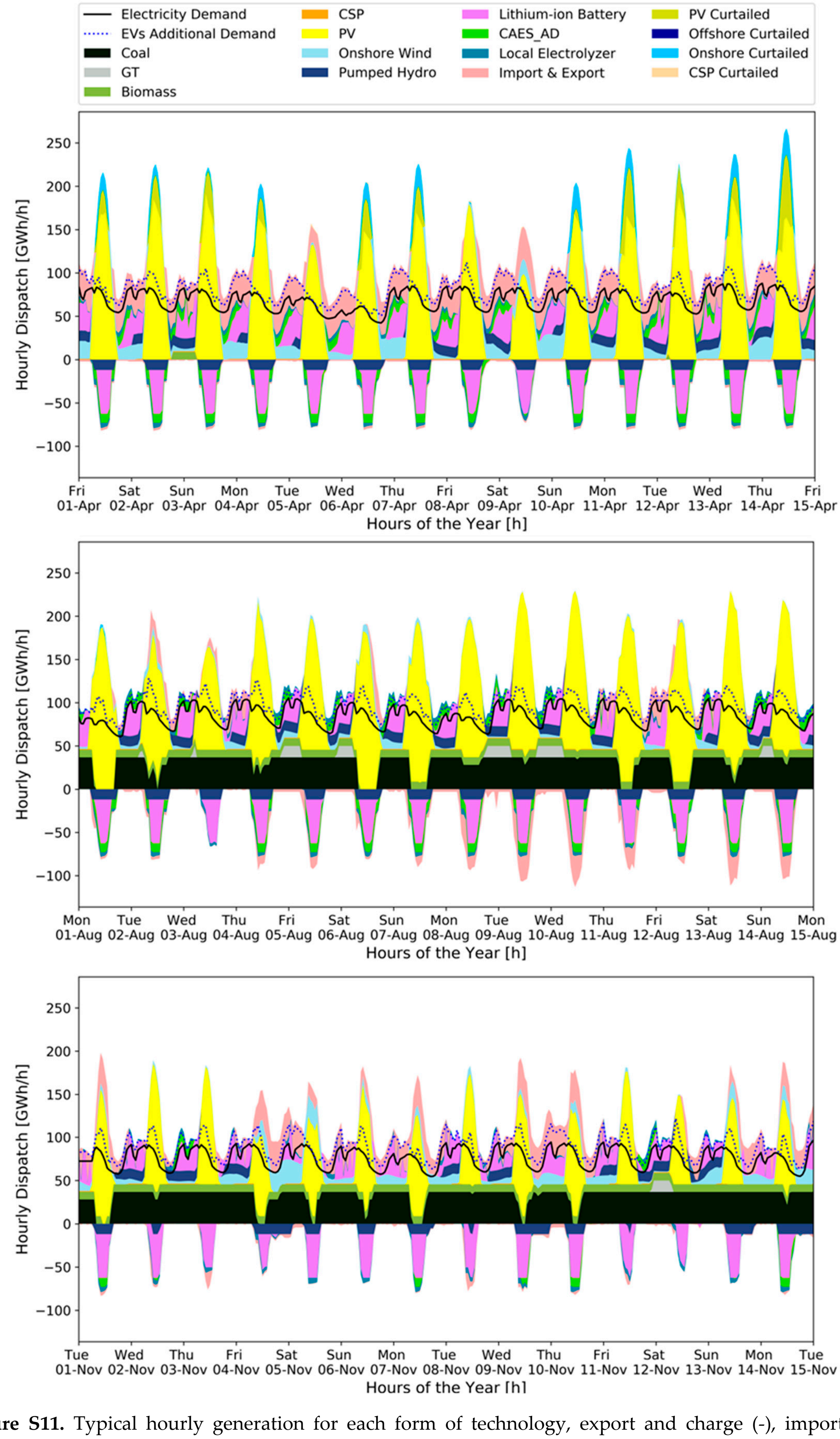

Figure S11. Typical hourly generation for each form of technology, export and charge (-), import and discharge (+) to meet power demand in Hebei in April, August and November in 2050.

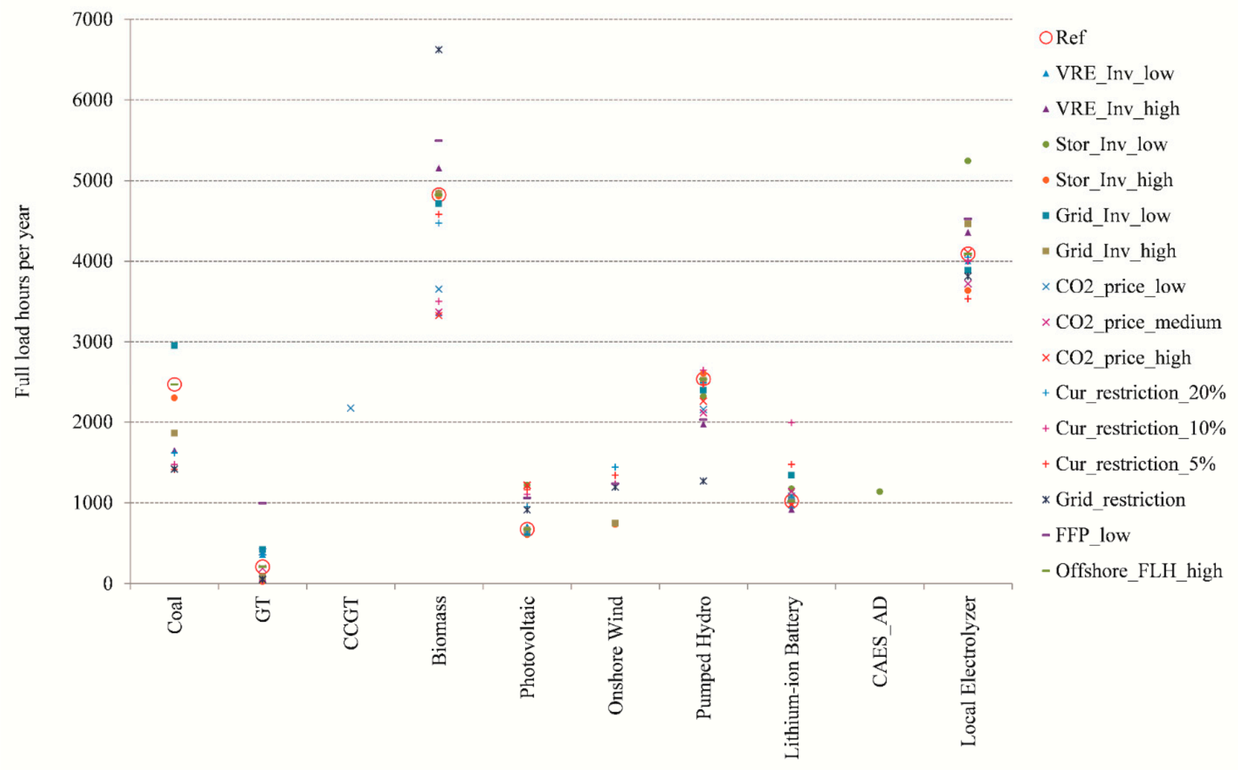

Figure S12. Influence of sensitivity analysis on full load hours in Beijing in 2050.

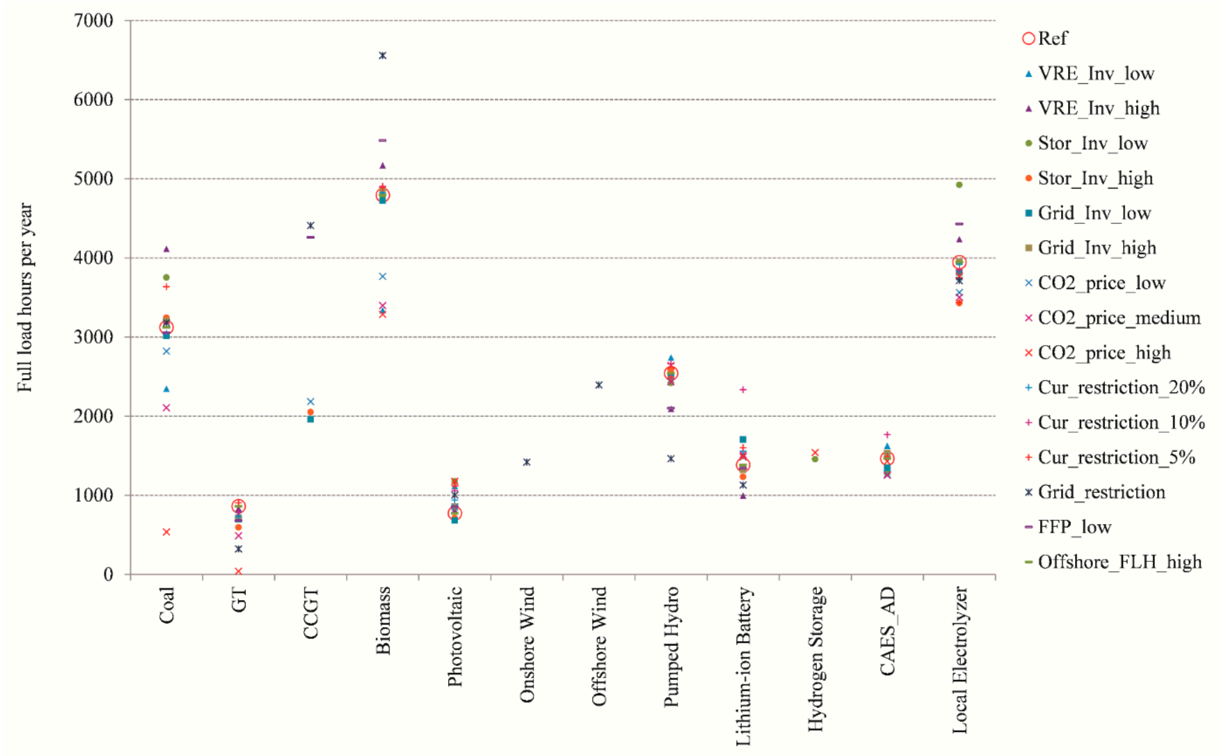

Figure S13. Influence of sensitivity analysis on full load hours in Tianjin in 2050.

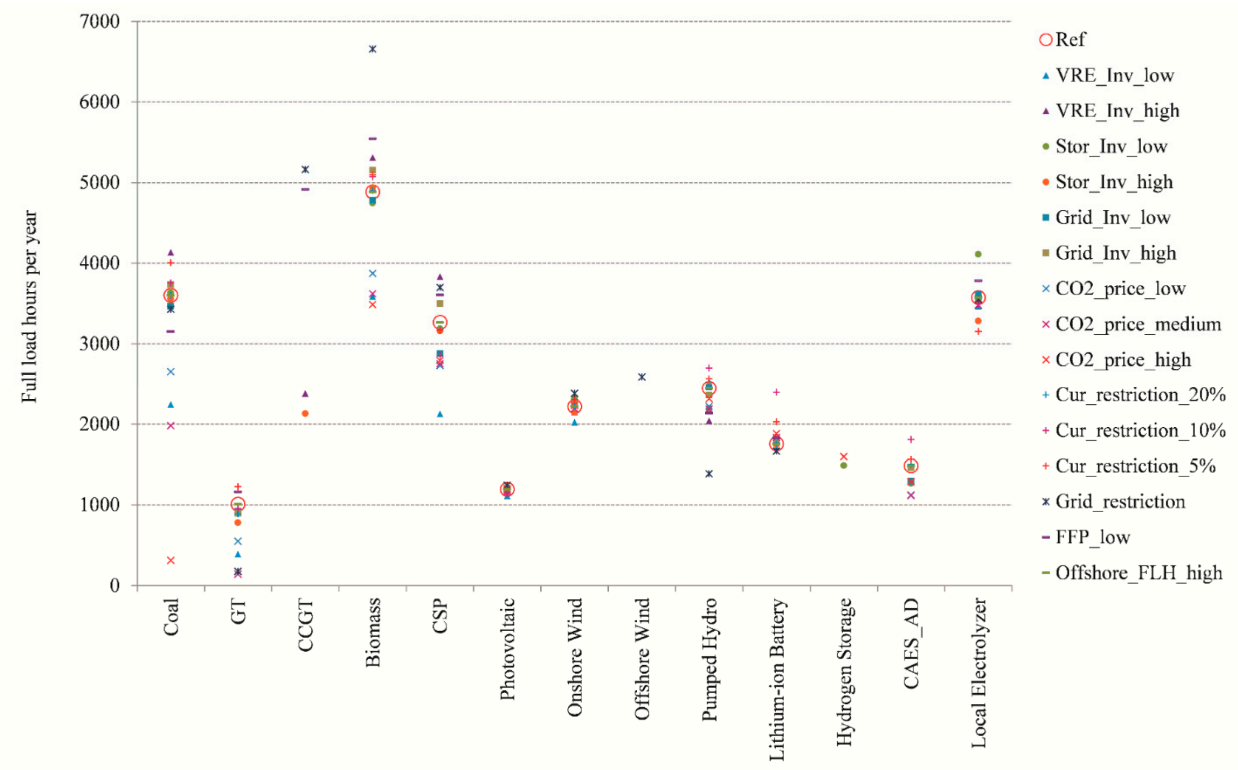

Figure S14. Influence of sensitivity analysis on full load hours in Hebei in 2050.

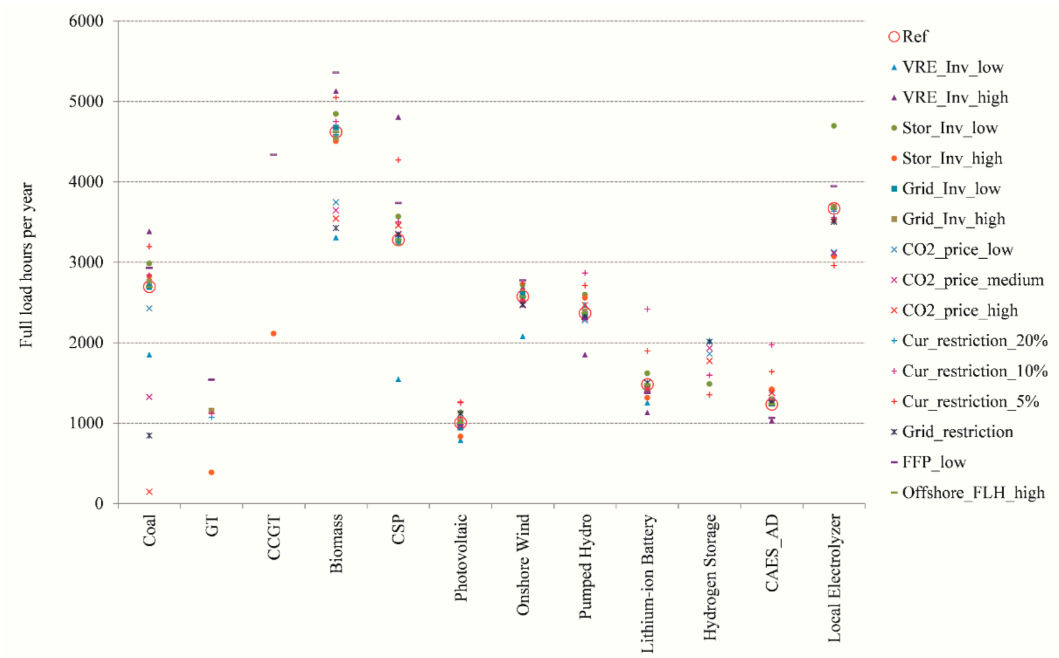

Figure S15. Influence of sensitivity analysis on full load hours in Inner Mongolia in 2050.

References

1. G. He, A.-P. Avrin, J.H. Nelson, J. Johnston, A. Mileva, J. Tian, and D.M. Kammen, "SWITCH-China: A Systems Approach to Decarbonizing China's Power System," *Environmental Science & Technology*, vol. 50, 2016, pp. 5467–5473.
2. T. Burandt, B. Xiong, K. Löffler, and P.-Y. Oei, "Decarbonizing China's energy system – Modeling the transformation of the electricity, transportation, heat, and industrial sectors," *Applied Energy*, vol. 255, 2019, p. 113820.
3. H. Liu, G.B. Andresen, and M. Greiner, "Cost-optimal design of a simplified highly renewable Chinese electricity network," *Energy*, vol. 147, Mar. 2018, pp. 534–546.
4. N. Zhang, Z. Hu, B. Shen, G. He, and Y. Zheng, "An integrated source-grid-load planning model at the macro level: Case study for China's power sector," *Energy*, vol. 126, 2017, pp. 231–246.
5. Y. Cheng, N. Zhang, D.S. Kirschen, W. Huang, and C. Kang, "Planning multiple energy systems for low-carbon districts with high penetration of renewable energy: An empirical study in China," *Applied Energy*, vol. 261, 2020, p. 114390.
6. L.-C. Ye, H.X. Lin, and A. Tukker, "Future scenarios of variable renewable energies and flexibility requirements for thermal power plants in China," *Energy*, vol. 167, 2019, pp. 708–714.
7. Y. Li, Z. Lukszo, and M. Weijnen, "The impact of inter-regional transmission grid expansion on China's power sector decarbonization," *Applied Energy*, vol. 183, 2016, pp. 853–873.
8. B.-W. Yi, J.-H. Xu, and Y. Fan, "Coordination of policy goals between renewable portfolio standards and carbon caps: A quantitative assessment in China," *Applied Energy*, vol. 237, 2019, pp. 25–35.
9. M. Xiao, S. Simon, and T. Pregger, "Scenario analysis of energy system transition - A case study of two coastal metropolitan regions, eastern China," *Energy Strategy Reviews*, vol. 26, 2019, p. 100423.
10. Y. Scholz, "Renewable energy based electricity supply at low costs: development of the REMix model and application for Europe," University of Stuttgart, 2012.
11. D. Stetter, "Enhancement of the REMix energy system model: Global renewable energy potentials, optimized power plant siting and scenario validation," University of Stuttgart, 2014.
12. G. He and D.M. Kammen, "Where, when and how much solar is available? A provincial-scale solar resource assessment for China," *Renewable Energy*, vol. 85, 2016, pp. 74–82.
13. F. Trieb, C. Schillings, M. O'Sullivan, T. Pregger, and C. Hoyer-Klick, "Global Potential of Concentrating Solar Power," *SolarPaces Conference Berlin*, 2009.
14. M. Caflisch, "Global Potentials for Concentrating Solar Power Electricity Generation - Adaptation of the REMix Renewable Energy Supply Model to Multi-Region Use," ETH Zürich, 2009.
15. R.M. ElShazly, "Feasibility of Concentrated Solar Power under Egyptian Conditions," 2011.
16. M.E. Mashena and N.A. Alkishriwi, "The Economics of Solar Thermal Electricity (STE) in Libya," *Proceedings of the International Conference on Recent Advances in Electrical Systems, Tunisia*, 2016.
17. K. Ummel and D. Wheeler, "Desert power: the economics of solar thermal electricity for Europe, North Africa, and the Middle East," 2008.
18. *Geographic Information System (GIS) Basic Data of China*, National Geomatics Center of China, 2017.
19. K. Song, J. Zhou, P. Zhang, and S. Kan, "Assessment of Biomass Power Potential on Provincial Scale and Analysis on Plan Target Quota," *Forum on Science and Technology in China*, vol. 0, 2016, pp. 124–129.
20. *Geothermal Potential*, Chinese Renewable Energy Industries Association (CREIA), .
21. *Potentials of pump hydro storage in China*, China Society for Hydropower Engineering, 2013.
22. NDRC, *13th National Five-Year Plan for Renewable Energy Development (可再生能源发展"十三五"规划)*, National Development and Reform Commission, 2016.
23. *Investigations of sea water pump storage potentials in China*, National Energy Administration, 2017.
24. L. Jia-kun, "Research on Prospect and Problem for Hydropower Development of China," *Procedia Engineering*, vol. 28, 2012, pp. 677–682.
25. Yuanan Hu and H. Cheng, "Displacement Efficiency of Alternative Energy and Trans-Provincial Imported Electricity in China," *Nature Communications*, vol. 8, 14590, 2017.
26. "China Renewable Energy Data Booklet (中国可再生能源数据手册)," 2017.
27. NDRC, *13th National Five-Year Plan for Power Development (电力发展"十三五"规划（2016-2020 年）)*, National Development and Reform Commission, National Energy Board, 2016.