Supporting Information

China's Sustainable Energy Transition Path to Low-carbon Renewable Infrastructure Manufacture under Green Trade Barriers

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S1. Data Source

The carbon footprint per 1 kWh of electricity produced from the seven sources of coal, natural gas, nuclear power, hydropower, biomass, wind and solar was obtained from the Ecoinvent database (Table S1) and the specific data obtained are shown in Table S2.

Table S1. Referred database about the electricity generation by different energy sources

Energy sources	Database
Coal	Ecoinvent: electricity production, hard coal | electricity, high voltage | Cutoff, U
Natural gas combined cycle	Ecoinvent: electricity production, natural gas, combined cycle power plant | electricity, high voltage | Cutoff, U
Natural gas combustion turbine	Ecoinvent: electricity production, natural gas, conventional power plant | electricity, high voltage | Cutoff, U
Biogas	Ecoinvent: heat and power co-generation, biogas, gas engine | electricity, high voltage | Cutoff, U
Hydro	Ecoinvent: electricity production, hydro, reservoir, non-alpine region | electricity, high voltage | Cutoff, U
	Ecoinvent: electricity production, hydro, run-of-river | electricity, high

	voltage | Cutoff, U
Nuclear power	Ecoinvent: electricity production, nuclear, boiling water reactor | electricity, high voltage | Cutoff, U Ecoinvent: electricity production, nuclear, pressure water reactor | electricity, high voltage | Cutoff, U
Pumped hydro storage	Ecoinvent: electricity production, hydro, pumped storage | electricity, high voltage | Cutoff, U
Wind	Ecoinvent: market for wind turbine, 4.5MW, onshore | wind turbine, 4.5MW, onshore | Cutoff, U
Photovoltaic	Ecoinvent: photovoltaic plant construction, 570kWp, multi-Si, on open ground | photovoltaic plant, 570kWp, multi-Si, on open ground | Cutoff, U
Lithium battery	Ecoinvent: battery production, Li-ion, rechargeable, prismatic | battery, Li-ion, rechargeable, prismatic | Cutoff, U

Table S2 Carbon footprint of electricity generation by different energy sources (kg CO_2-eq/kWh)

	Hydro	Bio	Solar PV	Wind	Nuclear	Natural gas	Coal
China	0.00402	0.22896	0.07723	0.03596	0.00758	0.68898	1.27529
America	0.01900	0.22896	0.04898	0.02011	0.00657	0.54627	1.16373
European Union	0.00594	0.22860	0.08811	0.02695	0.00616	0.61006	1.05712
Japan	0.00636	0.22896	0.08278	0.02601	0.00672	0.60248	1.01755
India	0.00636	0.22896	0.07723	0.03328	0.00642	0.57831	1.56781

Based on the World Energy Outlook report from the International Energy Agency, the electricity produced by different energy sources in China, the United States, the European Union, Japan, and India in 2022, 2030, and 2050 was obtained[1] (Table S3). Renewable energy is assumed to be hydropower and biomass, with the ratio of the two simulated according to IEA's "Net Zero by 2050: A Roadmap for the Global Energy Sector"[2] (Table S4).

Table S3 Predicted power generation in various countries or regions (TWh)

	Year	Renewables	Solar PV	Wind	Nuclear	Nuclear	Coal
China	2022	2681.36	429.15	762.39	417.71	257.20	5536.03
	2030	6073.78	2294.43	1962.95	642.16	348.57	4662.43
	2050	12663.80	6801.49	3875.94	1246.67	371.06	2213.45

	2022	972.90	185.27	442.39	804.25	1746.84	914.22
US	2030	2205.13	828.68	1001.43	825.20	1538.16	205.91
	2050	5509.62	3069.24	1916.84	803.93	513.12	11.51
	2022	1085.25	201.54	419.84	606.85	546.54	483.69
EU	2030	2176.79	625.67	984.77	623.38	333.90	87.90
	2050	3712.56	1186.32	1789.74	575.66	104.22	3.39
	2022	224.83	94.68	9.58	60.18	358.68	333.49
Japan	2030	384.79	161.63	64.18	207.22	215.89	195.68
	2050	650.65	233.88	208.34	205.92	91.83	65.77
	2022	398.87	105.26	79.35	49.57	39.41	1270.29
India	2030	980.95	480.10	189.03	127.60	83.10	1472.44
	2050	4148.80	2499.14	1071.14	336.58	174.83	1028.92

Table S4 Hydro and biomass ratios in different years

Year	Hydro	Biomass
2020	0.16	0.03
2030	0.15	0.05
2050	0.12	0.08

Based on the above data, the national average electricity carbon footprint of each country or region in 2022, 2030 and 2050 is calculated by weighted average, and the calculation results are shown in Table S5.

Table S5 Carbon footprint of a hybrid grid for every 1kWh of electricity produced (kg CO_2-eq/kWh)

	2022	2030	2050
China	0.83	0.56	0.14
US	0.46	0.25	0.08
EU	0.33	0.12	0.07
Japan	0.58	0.35	0.17
India	1.16	0.91	0.35

The carbon footprint of the transportation phase is the greenhouse gas emissions generated by the sale of products from the place of production to the place of consumption through different modes of transportation. This article mainly considers road, rail and shipping, of which road transportation includes diesel vehicles and electric vehicles. The carbon footprint of electric vehicles is calculated through the Ecoinvent database and literature research[3, 4], and the whole life cycle model of electric vehicles from raw material mining to waste recycling is established. The weight of the product and the carbon footprint factors of different modes of transport are shown in Table S6-7.

Table S6 The weight per unit of product[5-13]

	Wind turbine	Photovoltaic panel	Lithium battery
Unit	t/kWp	kg/MW	kg/kWh
Weight	140	52.6	9

Table S7 Carbon footprints of different modes of transport (kg CO_2-eq/(t*km))

	Value	Data sources
Lorry	0.08902	Ecoinvent: transport, freight, lorry >32 metric ton, EURO6 | transport, freight, lorry >32 metric ton, EURO6 | Cutoff, S
	0.17041	Ecoinvent: transport, freight, lorry 16-32 metric ton, EURO4 | transport, freight, lorry 16-32 metric ton, EURO4 | Cutoff, U
Train	0.03564	Ecoinvent: transport, freight train, electricity | transport, freight train | Cutoff, S
Sea	0.00931	Ecoinvent: transport, freight, sea, container ship | transport, freight, sea, container ship | Cutoff, S

S2. Scenario Analysis

Based on SSPs and temperature targets, namely no climate target (NCT)[14], a deep de-carbonization target (2°C)[15], and a net-zero emissions target (1.5°C)[16], the Li[17] team projected changes in the energy mix of China's power sector from 2020 to 2050. Based on this data, SSP1+1.5°C, SSP2+2°C, and SSP3+NCT, which represent the low-carbon scenario, the medium-carbon scenario, and high carbon scenario, were selected after calculating and screening the electricity carbon footprint under each pathway. This is shown in Figure S1 and S2.

In Figure S1, mix electricity has the lowest carbon footprint of 0.43 kg CO_2-eq/kWh (2050) under SSP1. The highest is SSP5, which is consistently maintained at around 1.03 kg CO_2-eq/kWh. SSP2 serves as an intermediate pathway with a carbon footprint of 0.70 kg CO_2-eq/kWh in 2050.

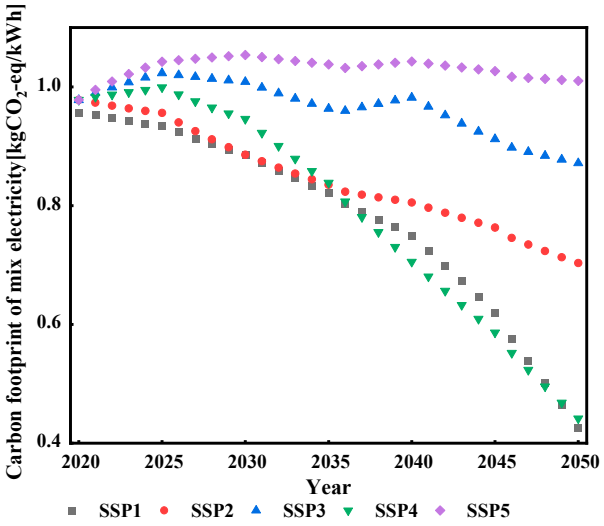

Figure S1 Changes in the carbon footprint of national electricity mix under the effect of various shared socio-economic pathway (SSPs);

The intermediate path SSP2 was chosen to demonstrate the impact of the temperature target on the carbon footprint of mix electricity. Stricter temperature targets will promote grid decarbonization, which is 65.99% and 85.58% lower than NCT, respectively.

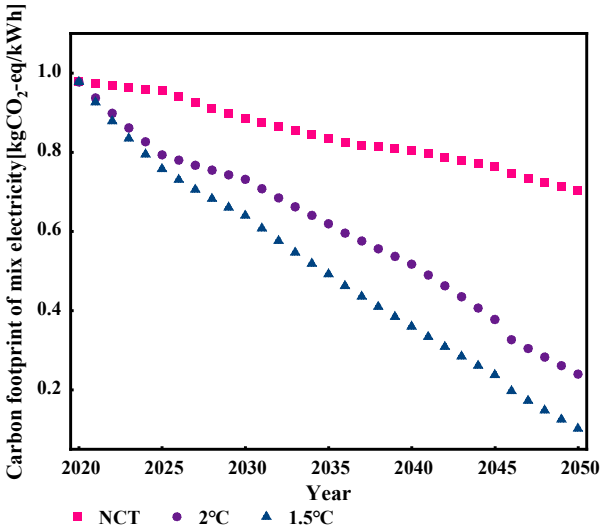

Figure S2 Changes in the carbon footprint of national electricity mix under the impact of different climate targets under SSP2

Then, taking into account the future development of CCS technologies to promote the decarbonization of the power sector, this paper sets different CCS penetration ratios. as shown in Table S7.

Table S7 Qualitative description of different CCS installation ratios

	No CCS	50%CCS	100%CCS
Description	CCS is not installed	50% of coal-fired power plants are equipped with CCS	All thermal power plants are equipped with CCS

Figure S3 shows the effect of different CCS permeability on the change of carbon footprint of the national power structure at SSP2+2℃, and the different permeability rates decreased by 14.87%, 17.47%, 21.17% and 49.65%, respectively compared with No CCS (2050).

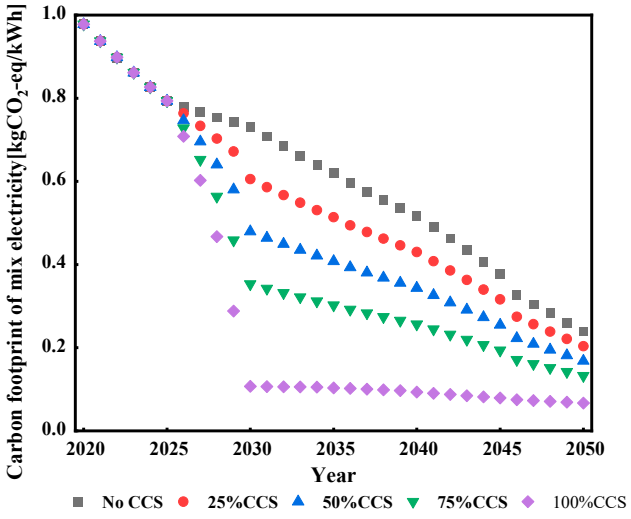

Figure S3. Changes in the carbon footprint of national electricity mix under the impact of different proportions of CCS installation (penetration rate in 2050) under the SSP2 scenario of 2°C.

Based on the above analysis, three special scenarios of SSP1+1.5℃+100%CCS, SSP2+2℃+50%CCS and SSP5+NCT+No CCS were selected to explore the impact of the power sector on low-carbon power infrastructure under extreme and intermediate scenarios.

The distance of transportation is related to the mode and location of transportation. According to the transportation scenario matrix set in the text, the transportation distances of different locations are shown

in Table S8.

Table S8 Distances at different locations (km)

Transport	Location				
Train	SH-Lhasa	Urumqi-Lhasa	Urumqi-Hamburg	SH- Urumqi	Urumqi-India
Distance	4373	2814	7000	4139	1793
Highway	SH-Urumqi	SH-Lhasa	Urumqi-Lhasa		
Distance	3883	4126	2716		
Shipping	SH-Tokyo	SH-India	SH- Hamburg	SH-US	
Distance	1941	8653	19961	9997	

Note: SH：Shanghai, China

S3. Electricity decarbonization scenarios

Based on the 2020-2050 structure of China's power grid projected in the literature[17], the average carbon footprint of China's electricity under three scenarios is calculated.

Table S9 China's average electricity carbon footprint under the three scenarios (kg CO_2-eq/kWh)

Year	SSP1+1.5℃+100%CCS	SSP2+2℃+50%CCS	SSP5+NCT+0%CCS
2020	0.95672	0.95672	0.95672
2021	0.91424	0.93686	0.99488
2022	0.87415	0.89778	1.00890
2023	0.83736	0.86086	1.02128
2024	0.80350	0.82593	1.03228
2025	0.77223	0.79283	1.04211
2026	0.68958	0.74569	1.04462
2027	0.58527	0.69473	1.04703
2028	0.45474	0.63944	1.04927
2029	0.28697	0.57926	1.05136
2030	0.19648	0.47853	1.05331
2031	0.19256	0.46328	1.04974
2032	0.18922	0.44852	1.04639
2033	0.18611	0.43423	1.04324

2034	0.18323	0.42039	1.04028
2035	0.17545	0.40697	1.03748
2036	0.16472	0.39206	1.03154
2037	0.15659	0.37943	1.03459
2038	0.14865	0.36696	1.03755
2039	0.14087	0.35460	1.040373
2040	0.13314	0.34206	1.04252
2041	0.12634	0.32479	1.03896
2042	0.11967	0.30738	1.03556
2043	0.11313	0.28973	1.03231
2044	0.10670	0.27179	1.02922
2045	0.10180	0.25344	1.02626
2046	0.09354	0.22102	1.01658
2047	0.08969	0.20716	1.01476
2048	0.08586	0.19343	1.01303
2049	0.08204	0.17979	1.01139
2050	0.07754	0.16627	1.00982

S4. Transport decarbonization scenarios

The carbon footprint of the transportation process after the decarbonization of the grid in 2050 can be calculated from the total carbon footprint of rail transportation, the electricity consumed by rail transportation, the current carbon footprint per unit of electricity, and the carbon footprint per unit of electricity in 2050, as shown in Tables S10 and S11 Estimated value.

The electric train operation is also based upon the corresponding RER dataset in. However, also in this case the Chinese official statistics give a much lower energy use that the European ones, 3.6-time lower electricity consumption per t*km. Again, the original value has been increased by a factor of 2.67 and the uncertainty factor has been increased compared to the corresponding item in literature[18].

Table S10. Calculation data and sources of the 2050 carbon footprint of rail transport in Europe

Year	Category	Unit	Value
Fixed value	Electricity consumption	kWh	0.40924

2020	Electricity carbon footprint	kg CO_2-eq/kWh	0.04780
2050	Electricity carbon footprint	kg CO_2-eq/kWh	0.06675

Table S11. Calculation data and sources of the 2050 carbon footprint of rail transport in China

Year	Category	Unit	Value
Fixed value	Electricity consumption	kWh	0.02960
2020	Electricity carbon footprint	kg CO_2-eq/kWh	1.02534
2050	Electricity carbon footprint	kg CO_2-eq/kWh	0.07555

Table S12 Carbon footprint of electric trucks (kg CO_2-eq/(t*km))

Year	Value	Year	Value
2020	0.16134	2050	0.01595

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