Supplementary Information

Cost and Low-Carbon Competitiveness of Electrolytic Hydrogen in China

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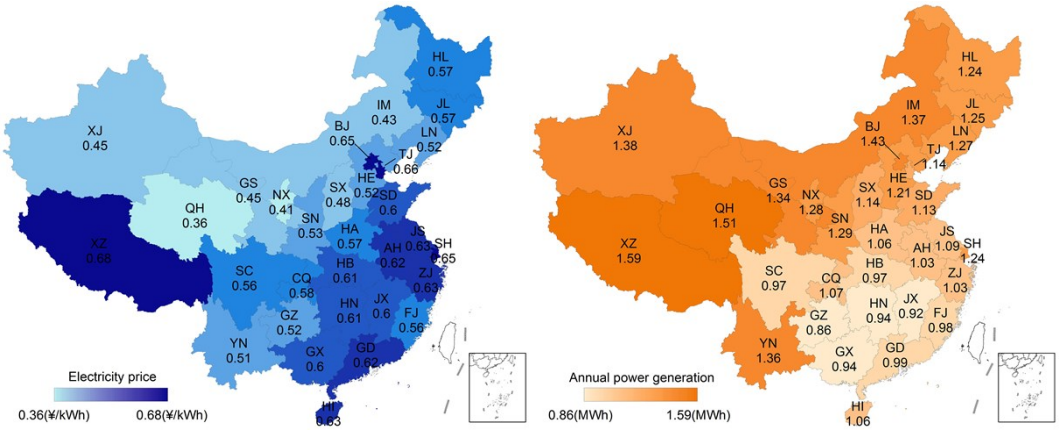
S1 Optimization model data and parameters



a **b**

Figure S1. Province-level differentiated grid electricity prices and photovoltaic output. a Province-level electricity prices. **b** Annual power generation of a 1 kW solar panel in different provinces.

Table S1 Electricity price data

Province	Electricity price(¥/kWh)	Basic electricity price	
		Active power (¥/kWh-year)	Apparent power (¥/kVA-year)
Beijing (BJ)	0.6470	576	384
Tianjin (TJ)	0.6580	306	204
Shanghai (SH)	0.6460	504	336
Chongqing (CQ)	0.5807	432	288
Liaoning (LN)	0.5156	396	264
Jilin (JL)	0.5716	396	264
Heilongjiang (HL)	0.5708	396	264
Inner Mongolia (IM)	0.4328	336	228
Shanxi (SX)	0.4782	432	288
Hebei (HE)	0.5183	420	279.6
Shandong (SD)	0.6022	456	336
Shaanxi (SN)	0.5302	372	288
Ningxia (NX)	0.4110	360	240
Gansu (GS)	0.4532	342	228
Qinghai (QH)	0.3572	342	228
Xinjiang (XJ)	0.4508	342	228
Tibet (XZ)	0.6750	342	228
Sichuan (SC)	0.5574	468	312
Yunnan (YN)	0.5090	444	324
Guangxi (GX)	0.6011	408	330
Guizhou (GZ)	0.5217	420	312
Hunan (HN)	0.6147	360	240
Guangdong (GD)	0.6225	384	276
Fujian (FJ)	0.5602	432	288
Zhejiang (ZJ)	0.6344	480	360
Jiangxi (JX)	0.6043	468	312
Anhui (AH)	0.6192	480	360
Jiangsu (JS)	0.6268	480	360

Hubei (HB)	0.6069	504	336
Henan (HA)	0.5666	336	240
Hainan (HI)	0.6262	456	312

Table S2 System Configurations and Technology Assumptions of a PGHS

Parameter	Value
Photovoltaic (PV) investment cost (¥/kW)	5477.4[2]
Fixed operation and maintenance (O&M) cost of PV(¥/kW-year)	547.74
Power to hydrogen (P2H, using PEM electrolyzer as a representative) capital cost (¥/kW)	11665[3]
Fixed O&M and replacement cost of P2H (¥/kW-year)	647.4
Lifetime (years)	20[3]
Conversion efficiency of P2H(using hydrogen low heating value)	61.3 %[3]
Discount rate	3.85%

Table S3 Share of renewable power generation in provincial power grids

Province	Share[1]
Beijing (BJ)	0.0406
Tianjin (TJ)	0.0124
Shanghai (SH)	0.0198
Chongqing (CQ)	0.3559
Liaoning (LN)	0.2297
Jilin (JL)	0.1964
Heilongjiang (HL)	0.1213
Inner Mongolia (IM)	0.1546
Shanxi (SX)	0.0832
Hebei (HE)	0.1180
Shandong (SD)	0.0483
Shaanxi (SN)	0.1257
Ningxia (NX)	0.1713
Gansu (GS)	0.4708
Qinghai (QH)	0.7429
Xinjiang (XJ)	0.2133
Tibet (XZ)	0.9711
Sichuan (SC)	0.8895
Yunnan (YN)	0.9189
Guangxi (GX)	0.5594
Guizhou (GZ)	0.4026
Hunan (HN)	0.4519
Guangdong (GD)	0.2606
Fujian (FJ)	0.4906
Zhejiang (ZJ)	0.2287
Jiangxi (JX)	0.1679
Anhui (AH)	0.0561
Jiangsu (JS)	0.0784
Hubei (HB)	0.6010
Henan (HA)	0.0599
Hainan (HI)	0.3463

Table S4 Assumptions of coal gasification (CG) [4]

Years	Capital cost of CG (¥/kW_{h2})	Annual O&M cost of CG (¥/kW_{h2}-year)	Efficiency (LHV)	Emission factor ($kgCO_2/kgH_2$)
2020	18419	921	60 %	20.2
2025	18419	921	60 %	20.2
2030	18419	921	60 %	20.2
2035	18419	921	60 %	20.2
2040	18419	921	60 %	20.2
2045	18419	921	60 %	20.2
2050	18419	921	60 %	20.2

Table S5 Assumptions of coal gasification (CG) with CCUS[4]

Years	Capital cost of CG (¥/kW_{h2})	Annual O&M cost of CG (¥/kW_{h2}-year)	Efficiency (LHV)	Emission factor ($kgCO_2/kgH_2$)
2020	19182	959	58 %	2.1
2025	19182	959	58 %	2.1
2030	19182	959	58 %	2.1
2035	19182	959	58 %	2.1
2040	19182	959	58 %	2.1
2045	19182	959	58 %	2.1
2050	19182	959	58 %	2.1

Table S6 Current and forecast price and technology levels of three electrolyzers[5]

Type	Current investment price (¥/kW)	2050 investment price (¥/kW)	Current Efficiency (LHV*)	Efficiency in 2050 (LHV*)
PEM	4830-12000	<1380	50-83 kWh/kg	<45 kWh/kg
Alkaline	3450-6900	<1380	50-78 kWh/kg	<45 kWh/kg
Solid oxide*	>13800	<2070	40-50 kWh/kg	<40 kWh/kg

* Low heating value (LHV) of hydrogen is 33.3 kWh/kg

* The heat for water vaporization in solid oxide electrolysers comes from the input power.

Table S7 Data and parameters for fossil fuel substitution by hydrogen in industry

Province	Product	Hydrogen consumption for producing per kg of product (kg) [6, 7]	Substitution percentage[8]	Annual production (10^6 ton)
Jiangsu	Ammonia	0.123	30 %	3.07
	Iron and steel	0.036	10 %	104.26
Yunnan	Ammonia	0.123	30 %	2.1
	Iron and steel	0.036	10 %	19.25

Table S8 Assumptions of CO_2 price and Coal price

Years	Low CO_2 price (¥/ton)*	High CO_2 price (¥/ton)*	Coal price (¥/ton)
2020	15	60	592[10]

2025	37.5	150	655[11]
2030	60	240	681
2035	82.5	330	706
2040	105	420	731
2045	127.5	510	757
2050	150	600	782

* Low CO_2 price is set at half of the predicted value of the State Grid Energy Research Institution[9].

* High CO_2 price is set twice the value predicted by the State Grid Energy Research Institution[9].

Table S9 Drops of Per capita CO_2 emissions compared with 2005[9]

Years	Drops of Per capita CO_2 emissions compared with 2005 (%)
2020	50
2025	60
2030	70
2035	75
2040	80
2045	85
2050	90

Table S10 Assumptions of PV and P2H

Years	Capital cost of PV (¥/kW)	Capital cost of P2H (¥/kW)	P2H Efficiency (LHV*)
2020	5477[2]	11665[3]	61.3%[3]
2025	4400	8278	64%
2030	3350	6209[12]	69%[7]
2035	2300[9]	5002	71.5%
2040	2166	3795	74%[7]
2045	2033	2588	78.5%
2050	1900[9]	1380[8]	83%[8]

* Low heating value (LHV) of hydrogen is 33.3 kWh/kg

Table S11 Assumptions of share of renewable power generation nationwide

Years	Share
2020	27.9 %[13]
2025	40 %
2030	50 %[14]
2035	57.5 %
2040	65 %
2045	72.5 %
2050	80 %

S2 Provincial LCOH falls by applying the time-of-use price

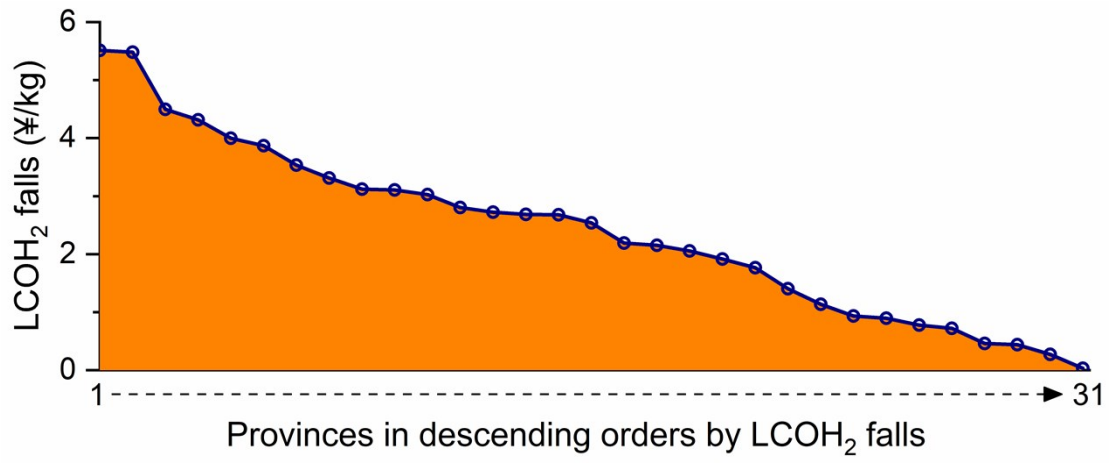


Figure S2. Provincial LCOH falls by applying the time-of-use price.

S3 Power purchased from the grid and PV output in Beijing within a week

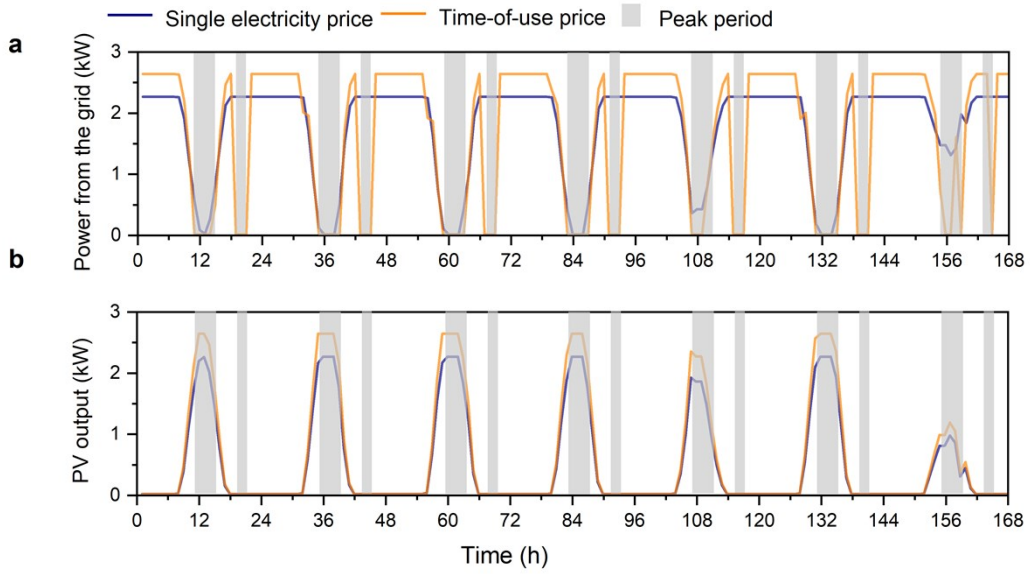


Figure S3. Power purchased from the grid and PV output in Beijing within a week. The capacity factor in single electricity price and time-of-use price scenarios is 1 and 0.86, respectively.

S4 Annual bills paid by the provincial governments under the three subsidies

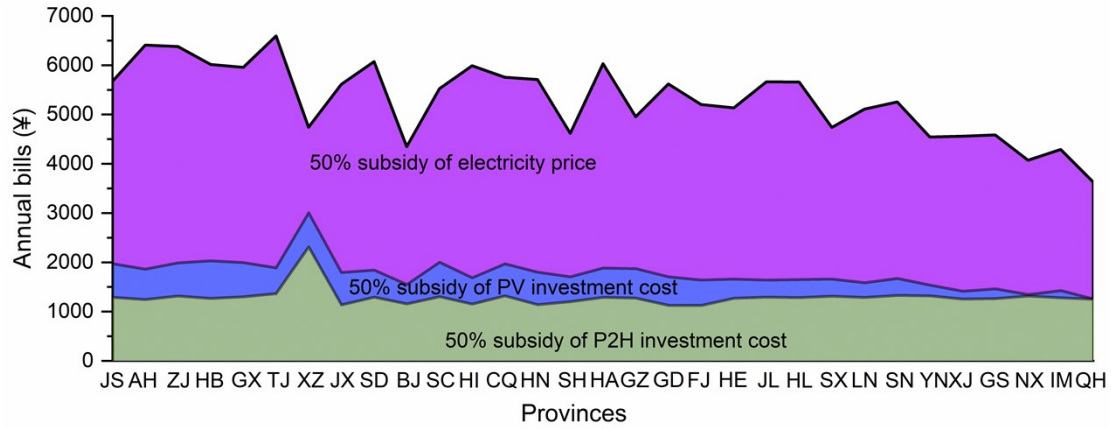


Figure S4. Annual bills paid by the provincial governments under the three subsidies.

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