



Technical Feasibility of a 100% Wind-Water-Solar Renewable Energy System for China: Capacity, Land Use and Grid Integration Assessment

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Abstract. This report assesses the feasibility of transitioning China to a 100% clean, renewable energy system based on wind, water, and solar (WWS) technologies. Using national energy consumption data, end-use demand is converted to electricity requirements and allocated among wind, solar, and hydropower. Device counts, installed capacity, and associated land area are estimated for each technology using typical capacity factors and power densities. Results indicate that supplying China's annual energy demand of approximately 15,177.54 TWh would require around 3,465 GW of solar capacity, 1,629 GW of wind capacity, and 770 GW of hydropower. The total land and sea area needed is approximately 540,957 km², representing only 5.6% of China's land area, with rooftop PV contributing significantly to land-use reduction. These findings confirm that a 100% WWS energy transition in China is technically achievable with proper resource allocation, strategic siting, and integration of storage and grid expansion measures.

Keywords: Energy transition, Wind-water-solar (WWS) system, Grid integration, Device requirements, Energy storage.

1 Introduction

According to International [1], China remains the world's largest energy consumer and carbon emitter, largely because fossil fuels still dominate energy use across industry, households, transport, and commerce (see Fig. 1). The consequences are familiar: high greenhouse gas emissions, degraded air quality, and substantial public-health costs. World Health Organization (2024) notes that air pollution is a leading cause of premature deaths globally, which brings the discussion back to energy choices [2].

This report examines whether a 100% renewable system based on wind, water, and solar (WWS) is technically feasible for China. We estimate the electricity demand to be supplied by WWS, translate that demand into installed capacities and device counts, and assess land and sea area requirements. We also consider the contribution of rooftop PV (assumed at 20% of total solar capacity) to relieve pressure on ground-mounted sites and ask whether the spatial needs are compatible with China's geography and

infrastructure. Taken together, these steps provide a quantitative basis for judging the scale, siting, and practicality of a 100% WWS transition in China.

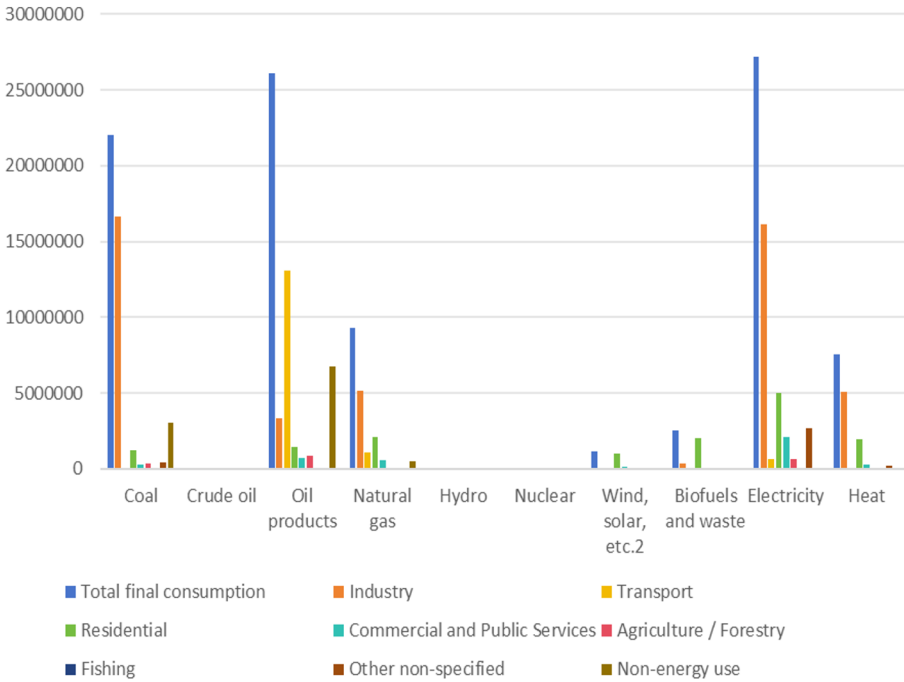


Fig. 1. China's energy demand in 2022(TJ)

2 Results and Analysis

The analysis follows a multi-step approach to estimate the renewable energy capacity, device requirements, and land-use implications of transitioning China to a 100% wind, water, and solar (WWS) energy system.

2.1 Determine Total End-Use Electricity Demand

Baseline annual end-use energy demand was obtained from national statistics (provided in course data) and converted from final energy consumption (TJ) to TWh for consistency. By using the data shown in table 1, the end-use energy for each sector can be obtained.

Table 1 shows the process of converting the final energy consumption (TJ) of each industry into electricity demand (TJ) through efficiency factors, which is the basis for subsequent WWS electricity allocation.

Table 1. End-use energy for each sector

Sector	Fuel	BAU Energy (TJ)	Factor	WWS Electricity (TJ)
Industry	Coal	16,655,293	0.82	13,657,340
Industry	Oil products	3,299,681	0.82	2,705,738
Industry	Natural gas	5,139,637	0.82	4,214,502
Industry	Biofuels & waste	352,679	0.82	289,197
Industry	Heat	5,094,081	0.25	1,273,520
Industry	Electricity	16,159,485	1	16,159,485
Transport	Oil products	13,047,919	0.19	2,479,105
Transport	Natural gas	1,059,674	0.19	201,338
Transport	Biofuels & waste	89,803	0.19	17,063
Transport	Electricity	633,361	1	633,361
Residential	Coal	1,199,277	0.2	239,855
Residential	Oil products	1,474,589	0.2	294,918
Residential	Natural gas	2,064,926	0.2	412,985
Residential	Biofuels & waste	2,022,527	0.2	404,505
Residential	Heat	1,936,138	0.25	484,035
Residential	Electricity	5,016,908	1	5,016,908

2.2 Allocate End-Use Demand to WWS Technologies

China holds a leading position across all three major renewable technologies. Wind capacity reached about 521 GW in 2024—an 18% rise with nearly 80 GW added that year [3], cementing China’s frontrunner status [4]. Solar grew even faster to roughly 887 GW in 2024, an unprecedented 45% annual increase with around 277 GW of new additions ; China now accounts for over half of global PV capacity (Todorović, 2024) [5]. Hydropower stood at approximately 436 GW in 2024, expanding by 3.2% (13.8 GW). Although hydro grows more steadily than wind and solar, it remains the system’s backbone, supplying roughly one-fifth of renewable output and providing essential flexibility. Taken together, these trends indicate that wind and solar will drive the next phase of expansion, with hydropower underpinning stability and integration.

Reflecting this balance, we allocate end-use demand across WWS as 40% wind, 40% solar, and 20% hydropower. This split aligns with China’s large wind/solar potential and substantial existing hydro base, while keeping ~80% of supply shared between wind and solar. Let the total annual WWS electricity demand be E_{Total} (TWh); the allocations are:

$$E_{wind} = 0.40E_{Total}, E_{solar} = 0.40E_{Total}, E_{hydro} = 0.20E_{Total} \tag{1}$$

Then as a result, the WWS electricity for each wind, water, solar can be calculated as:

$$E_{Total} = 54639114 \text{ TJ} \approx 15177.54 \frac{\text{TWh}}{\text{yr}} \tag{2}$$

$$E_{wind} = E_{solar} = \frac{15177.54 \text{TWh}}{\text{yr}} \times 0.4 = 6,071.02 \frac{\text{TWh}}{\text{yr}} \quad (3)$$

$$E_{hydro} = \frac{15177.54 \text{TWh}}{\text{yr}} \times 0.2 = 3,035.51 \frac{\text{TWh}}{\text{yr}} \quad (4)$$

2.3 Determine Device Requirements

To estimate the number of devices required to meet China's projected 100% WWS electricity demand, key assumptions were made for wind, solar, and hydropower based on recent data and technology trends.

Wind Energy. Wind generation is assumed to be 70 % onshore and 30 % offshore, reflecting the dominance of land-based projects in northern provinces and the rapid growth of coastal developments [6] [7].

For onshore wind, Inner Mongolia was selected as a representative site, with average wind speeds of 6–7 m s⁻¹ at 100 m height [8], a 5 MW turbine, and a capacity factor (CF) of 0.40 [9].

For offshore wind, the China Sea shows typical mean speeds of 9–10 m s⁻¹ [10], using 12 MW turbines with CF = 0.504 [11].

In 2024, China added 357 GW of new wind + solar capacity [12], demonstrating the feasibility of these assumptions.

Solar Energy. Solar generation is divided into 20 % rooftop PV and 80 % utility-scale PV, consistent with China's "whole-county rooftop PV" initiative [9].

A capacity factor of 0.20 and 400 W modules is assumed [13].

China reached 609 GW of installed PV capacity in 2023 [14], hosting over half of the world's total [5].

Hydropower. Hydropower uses a 45 % capacity factor and average plant size of 500 MW, consistent with large stations in the Yangtze and Mekong basins [1] [11].

Then the number of devices can be calculated as follows:

$$E = P \times 8760 \times \text{CF}$$

For onshore turbines:

$$N = \frac{E_{\text{onshore}}}{5 \times 8760 \times 0.4} = 242600$$

For offshore turbines:

$$N = \frac{E_{\text{offshore}}}{12 \times 8760 \times 0.504} = 192540$$

As for footprint and spacing area, the numbers can be calculated using the area factors given in figure 2.

WWS technology	Footprint (m ² /MW)	Spacing (km ² /MW)	Installed power density (MW/km ²)
Onshore wind	3.22	0.05	20
Offshore wind	3.22	0.139	7.2
Wave device	700	0.033	30.3
Geothermal plant	3,290	0	304
Hydropower plant	502,380	0	2.0
Tidal turbine	290	0.004	250
Residential roof PV	5,230	0	191
Commercial/govt. roof PV	5,230	0	191
Solar PV plant	12,220	0	81.8
Utility CSP plant	29,350	0	34.1
Solar thermal for heat	1,430	0	700

Fig. 2. Area factors for WWS technology

For onshore turbines:

$$\text{Footprint} = \text{Onshore Capacity} \times \text{Area Factor} = 3.9 \text{ km}^2$$

$$\text{Spacing area} = \text{Onshore Capacity} \times \text{Area Factor} = 60663 \text{ km}^2$$

For offshore turbines:

$$\text{Footprint} = \text{Onshore Capacity} \times \text{Area Factor} = 1.34 \text{ km}^2$$

$$\text{Spacing area} = \text{Onshore Capacity} \times \text{Area Factor} = 57796 \text{ km}^2$$

Since the calculations for solar and hydro are quite similar, all the data will be shown in table 2 and table 3.

Table 2. Number of device required for WWS technology

Technology	Capacity (GW)	Device Type & Size	Estimated Number of Devices
Onshore Wind	1,213	5 MW turbines	242,600
Offshore Wind	416	12 MW turbines	34,650
Total Wind	1,629	–	277,250
Solar PV	3,465	400 W panels	8.66 billion modules
Hydropower	770	500 MW plants	1,540

Table 3. Area required for WWS technology

Technology	Area Type	Area (km ²)
Onshore Wind	Spacing	60,650
Offshore Wind	Spacing	57,809
Solar PV (Ground)	Land	33,874
Rooftop PV	Roof Area	3,624
Hydropower	Reservoirs	385,000
Total	All Types	540,957

3 Discussion

The results suggest that a 100% WWS system in China is technically achievable, given the country's resource base, manufacturing depth, and ongoing investments in transmission and storage. Below we discuss device requirements, spatial feasibility, system integration, and wider implications.

3.1 Device Requirements and Manufacturing Capacity

Meeting full WWS demand implies roughly 277,250 wind turbines, about 8.66 billion PV modules (400 W each), and around 1,540 hydropower plants (Section 3). These numbers are large but not detached from China's industrial reality. The country already produces >80% of global PV components and a substantial share of wind equipment [15]. In practical terms, sustained investment in innovation and supply-chain efficiency—especially blades, inverters, batteries, and power electronics—could support the required manufacturing cadence. The headline volumes also align with recent annual additions shown in Fig. 2 and give confidence that multi-year deployment targets are within reach.

3.2 Land Use and Spatial Feasibility

The total estimated area linked to WWS deployment is ~540,957 km², or ~5.6% of China's land area (Table 3). This headline figure overstates direct land take: most on-shore wind "area" is turbine spacing, and underlying land generally remains in agricultural or grazing use; the physical foundations occupy only a small fraction of each site. Rooftop PV—assumed at 20% of solar capacity—materially reduces the ground footprint and tracks ongoing "whole-county rooftop PV" programmes [16]. Hydropower accounts for the largest share of mapped area, but much of this reservoir surface already exists, implying only incremental expansion. If needed, part of the assumed hydro contribution can be reallocated to offshore wind to further ease land pressure without sacrificing energy output .

3.3 Grid Integration and System Flexibility

High shares of wind/solar shift the challenge from "how much" to "when/where." UHV lines move power west→east and cut curtailment. Storage must be layered: batteries for intra-day ramps; pumped hydro for multi-day swings. Put fast batteries near loads and PV; place long-duration storage near wind bases. On the demand side, time-of-use pricing, industrial load shifting, and aggregated DR trim peaks and net-load ramps. With better forecasting, shared reserves, and short-term markets that price flexibility, these pieces make variable supply behave like a reliable system.

3.4 Broader Implications

WWS cuts pollution and health costs, reduces exposure to fuel price shocks, and leans on domestic supply chains. Land use is manageable with rooftop PV and co-use on wind sites; hydro anchors seasonal balance. Key trade-offs remain: respectful siting, early corridor planning, and flexibility that grows in step with new GW. If those move together, wind/solar drive expansion; hydro keeps the system steady.

4 Conclusion

China can technically achieve a 100% wind-water-solar system under the assumptions used here. Meeting annual demand implies on the order of ~ 1.6 TW wind, ~ 3.5 TW solar PV, and ~ 0.8 TW hydropower, which corresponds to roughly 277,000 wind turbines, about 8.7 billion 400 W PV modules, and $\sim 1,540$ hydropower plants. The mapped area is $\sim 540,957$ km² ($\sim 5.6\%$ of land), though most onshore wind “area” is spacing that remains available for farming or grazing, a meaningful share of PV can be placed on rooftops, and most hydro surface area already exists. Combined with China’s manufacturing depth, expanding UHV transmission, and accelerating storage build-out, these results point to practical technical feasibility.

Policy priorities follow directly from the system needs: scale layered storage (batteries for intra-day ramps; pumped hydro for multi-day swings) in step with new wind and solar; strengthen inter-regional coordination through UHV corridors, shared reserves, and market-based dispatch to cut curtailment; and expand rooftop PV and land co-use on wind sites to ease ground footprint. Complementary measures—time-of-use pricing, industrial load shifting, aggregator demand response, and better forecasting—help convert variable generation into dependable supply.

This study uses typical capacity factors and high-level siting factors and does not model hourly reliability, multi-year weather variability, transmission bottlenecks, evolving costs, or local social-ecological constraints. Future work should couple these capacity estimates to hourly production-cost and adequacy modeling (e.g., LOLE/EUE) with provincial constraints, optimize the storage portfolio and demand response elasticity, assess hybrid plants (wind/solar/storage or power-to-hydrogen), and integrate life-cycle, recycling, financing, and staged roadmaps to 2030/2035/2050.

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