Global Energy Monitor

A Race to the Top

2023

CHINA

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Global Energy Monitor is a nonprofit research organization developing information on energy projects worldwide. Through its Global Solar Power Tracker and Global Wind Power Tracker projects, Global Energy Monitor provides annual updates on utility-scale solar and wind power facilities. Global Energy Monitor data is used by the International Energy Agency (IEA), the OECD Environment Directorate, UN Environment Programme, U.S. Treasury Department, and the World Bank. For more information, visit www.globalenergymonitor.org.

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ABOUT THE COVER

The cover photo shows a photovoltaic plant and a wind turbine in Dongtai pond located in Yancheng, Jiangsu Province, China. Image from iStock with credit to shenjun gong.

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FURTHER RESOURCES

For additional data on proposed and existing solar projects, see Summary Data of the Global Solar Power Tracker. For links to reports based on the Global Solar Power Tracker data, see Reports & Briefings. To obtain primary data from the Global Solar Power Tracker, see Download Data.

For additional data on proposed and existing wind projects, see Summary Data of the Global Wind Power Tracker. For links to reports based on the Global Wind Power Tracker data, see Reports & Briefings. To obtain primary data from the Global Wind Power Tracker, see Download Data.

Supplementary information on the methodology used in calculations for this report can be found on our methodology wiki page.

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Global Energy Monitor

A Race to the Top: China

CHINA'S QUEST FOR ENERGY SECURITY DRIVES WIND AND SOLAR DEVELOPMENT

Dorothy Mei, Martin Weil, Shradhey Prasad, Kasandra O'Malia, and Ingrid Behrsin

SUMMARY

With its focus on renewable energy development over the past 15 years, China has become the global renewable energy leader, hosting nearly half of the world's total operating wind and solar capacity. This ambitious push has been geographically widespread: every province and most counties are developing large utility-scale[1] solar and wind power. Mega wind and solar bases, primarily situated in China's northern and northwest deserts, anchor China's renewable energy ambitions and boast a prospective capacity greater than the 2022 total operating wind and solar capacity of the United States. These bases will serve as the centerpiece of China's renewable energy expansion and a cornerstone of the country's overall energy security strategy. China has skyrocketed to the top of the global wind and solar leaderboard through a combination of incentives and regulatory measures. As it looks to the future, the country is poised to maintain its leadership position by implementing ambitious initiatives that embrace innovative approaches to address the intermittent and volatile nature of wind and solar power, thus ensuring a more secure energy future.

Key Takeaways:

- China's operating large utility-scale solar capacity has reached 228 GW—more than the rest of the world combined. The majority of these installations are concentrated in the northern and northwest provinces of China, with Shanxi, Xinjiang, and Hebei ranking as the top three provinces in terms of large utility-scale solar capacity.
- China's combined onshore and offshore wind capacity has doubled from what it was in 2017 and now surpasses 310 GW. The highest concentration of operating wind capacity in China is in the northern and northwestern regions. Inner Mongolia, Hebei, and Xinjiang are the top three provinces in terms of operating wind capacity.

1. GEM catalogs all solar installations greater than 20 MW and all wind installations greater than 10 MW.

- Operating offshore wind capacity has reached 31.4 GW, and accounts for approximately 10% of China's total wind capacity and exceeds the operating offshore capacity of all of Europe.
- Approximately 379 GW of prospective large utility-scale solar capacity and the bulk of the 371 GW of prospective wind capacity identified are scheduled for installation by the end of 2025. It is therefore highly likely that the provincial targets (approximately 1,371 GW for wind and solar) will be achieved, surpassing the central government's target of 1,200 GW well ahead of 2030. This prospective capacity is enough to increase the global wind fleet by nearly 50% and grow global large utility-scale solar installations by 85% over current levels.
- China is now actively promoting power storage in conjunction with new wind and solar farms, exploring integrated generation, storage, and load management systems, and building dozens of green hydrogen plants using renewable energy as the power source.
- While all these technologies have the potential to mitigate the intermittency of wind and solar power generation, the current pace and scale are not yet sufficient to ensure that coal becomes a truly "supporting" power source. As currently conceived, the new renewables mega-bases in the northwest are likely to bundle wind and solar generation with close to equal amounts of electricity from newly built coal-fired stations.

1. REGIONAL BACKGROUND

Despite being the world's largest energy consumer and greenhouse gas producer, China has emerged as a global leader in renewable energy in recent years. China now holds the top position for both wind and solar energy, with each accounting for more than one-third of the world's total cumulative installed capacity.

Since the early 2000s, the Chinese government has heavily invested in renewable energy as a way to address the country's growing energy demands and pollution issues. As reported by BloombergNEF, global investment in renewable energy in 2022 approached nearly half a trillion US dollars for the first time, with China accounting for 55% of the world's total. Specifically, China has invested $164 billion in new solar installations and $109 billion in new wind installations, surpassing the combined investment figure from both the US and Europe.

To achieve its stated goal of peaking carbon emissions before 2030 and achieving carbon neutrality before 2060, China is accelerating its push towards renewable energy. Global Energy Monitor's Global Solar Power Tracker and Global Wind Power Tracker have identified approximately 379 GW of prospective[2] large utility-scale solar power capacity and 371 GW of prospective wind power capacity, which is roughly equal to China's current installed operating capacity. The majority of these projects are expected to be completed within the 14th Five-Year Plan (2021-2025),[3] with some additional large-scale initiatives anticipated to be finalized before 2030. With such a substantial pipeline of projects underway, China's world-leading renewable energy drive is set to not only continue, but likely even to accelerate.

2. Prospective projects are any projects that are either announced, in pre-construction, or under construction.
3. The 14th Five-Year Plan refers to the five-year economic and social development plan of China covering the period from 2021 to 2025.

2. OPERATING LARGE UTILITY-SCALE SOLAR AND WIND CAPACITY IN CHINA

National operating capacity overview

As of the first quarter of 2023, GEM's Global Solar Power Tracker catalogs nearly 228 GW[4] of operating large utility-scale solar capacity, establishing China as the country with the most operating solar capacity worldwide. This figure represents approximately 75% of the combined large utility-scale solar capacity of the entire Asian region and 52% of the global large utility-scale solar capacity.

China's combined onshore and offshore wind capacity have exceeded 310 GW,[5] which is roughly equal to the wind capacity of the other top seven countries globally, combined. Notably, operating offshore wind capacity has reached 31.4 GW, representing approximately 10% of China's total wind capacity, and nearly equivalent to the United States' prospective offshore wind capacity (36 GW).

Although both solar and wind capacities are increasing annually, the rate of growth for large utility-scale solar is more than twice that of wind. In 2022, the growth of commissioned large utility-scale solar was roughly 22%, while wind experienced a growth of 9% (Figures 1 and 2).

Figure 1: Total operating large utility-scale solar capacity by year

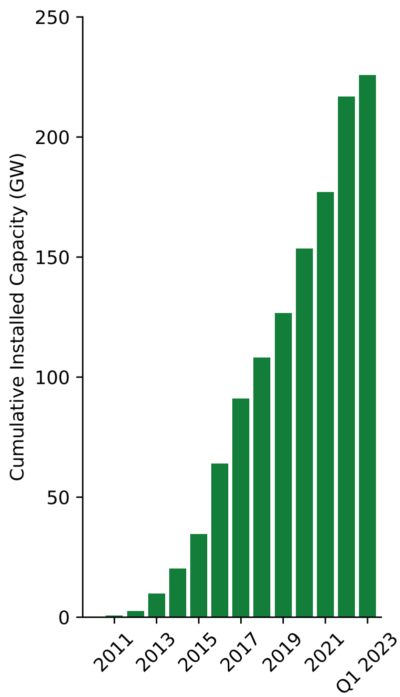
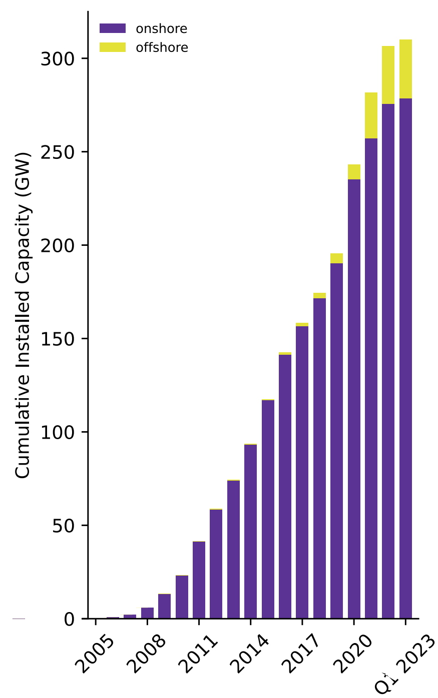


Figure 2 : Total operating onshore and offshore wind capacity by year



4. China reported a total of 392 GW of cumulative operating solar installed at the end of 2022. This figure is for all sizes of solar installations, including rooftop, commercial/industrial, and smaller-scale utility as well as large utility-scale. GEM's solar tracker only includes large utility-scale solar farm phases with a capacity of 20 MW or greater.

5. China reported a total of 365 GW of cumulative operating wind installed at the end of 2022. This figure is for all projects regardless of size. GEM's wind tracker is specifically focused on wind projects with a capacity threshold of 10 MW or greater.

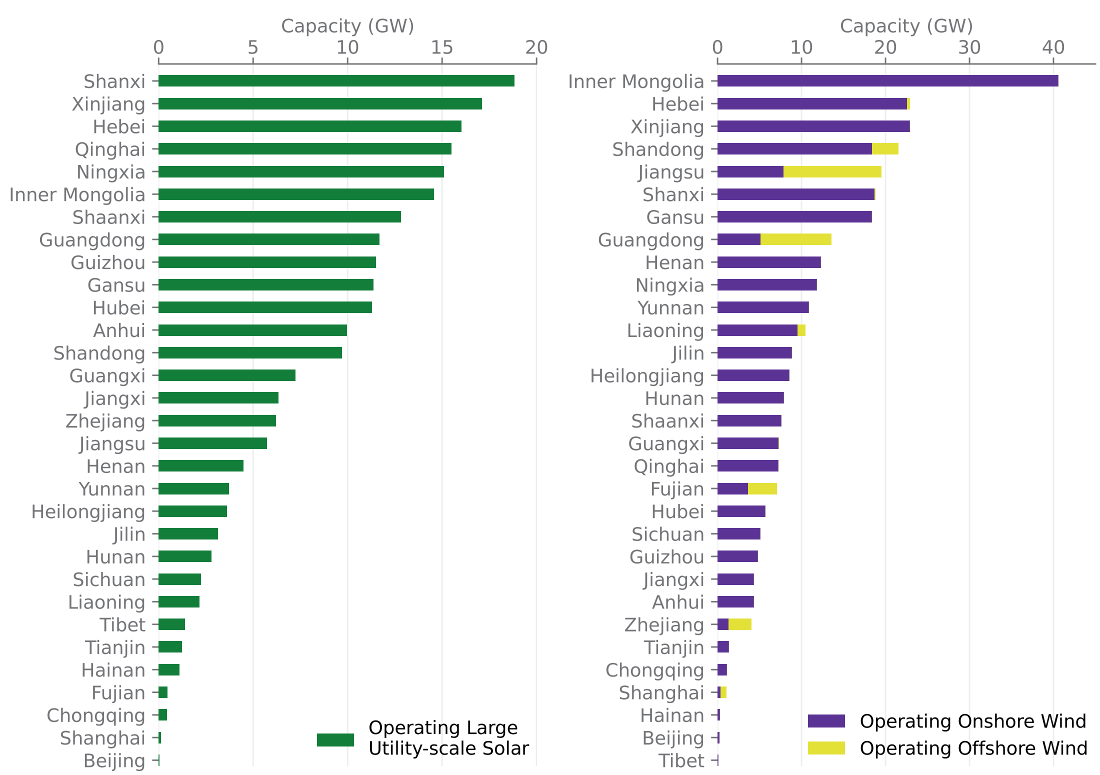
Provincial distribution of large utility-scale solar and wind capacity

Most operating large utility-scale solar installations are concentrated in China's north and northwest provinces (Map 1, on the next page). Shanxi, Xinjiang, and Hebei occupy the top three positions. Shanxi province, formerly known as China's coal capital, now leads the country in terms of operating large utility-scale solar capacity. Remarkably, it hosts nearly 19 GW of commissioned large utility-scale solar capacity. Xinjiang and Hebei provinces, both abundant in renewable energy resources, are close behind, contributing approximately 17 GW and 16 GW of operating capacity, respectively. The combined capacity of these top three provinces amounts to 52 GW, surpassing the total operating large utility-scale solar capacity of the United States in 2022.

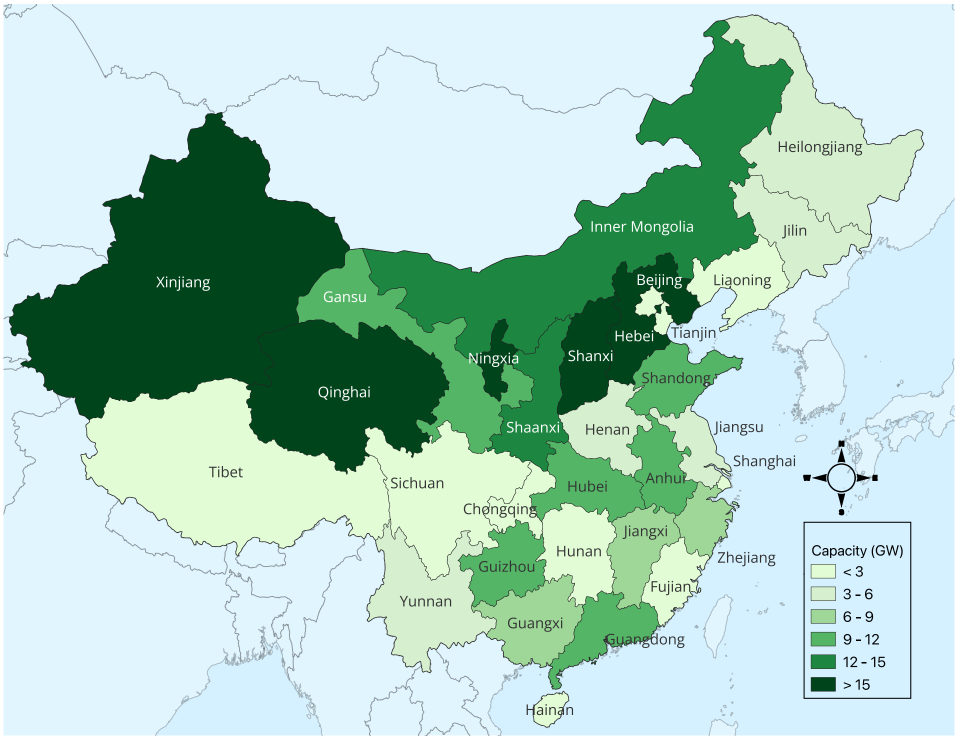
China's northern and northwestern regions feature the most operating wind capacity (Map 2, on the next page). As of the first quarter of 2023, Inner Mongolia leads China's provinces with approximately 41 GW of operating onshore wind capacity. Hebei and Xinjiang secure the next two positions, each providing 22.9 GW of operating wind capacity. The combined capacity of the top three provinces alone (approximately 87 GW) exceeds the combined capacity (62 GW) of operating wind installations in Brazil, Spain, and Canada.

In terms of offshore wind, the majority of the capacity (75%) is located in the provinces of Jiangsu, Guangdong, and Fujian. Among these provinces, Jiangsu, which is also home to the largest offshore wind farm in China (Jiangsu Qidong offshore wind farm), stands out as the largest contributor, accounting for about 12 GW, or 37% of the total. Guangdong and Fujian come in second and third, with these provinces contributing 8.5 GW and 3.5 GW, respectively, to China's total offshore wind capacity.

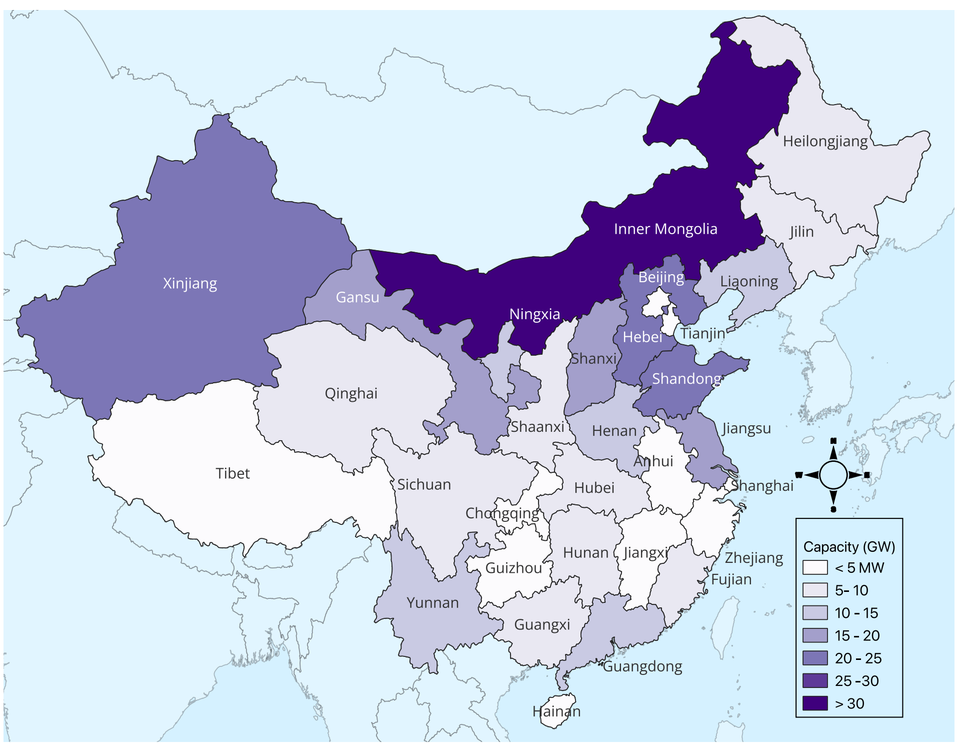
Figure 3: Operating large utility-scale solar and wind capacity by province



Map 1: Operating large utility-scale solar capacity in China



Map 2: Operating wind capacity in China



3. PROSPECTIVE LARGE UTILITY-SCALE SOLAR AND WIND CAPACITY IN CHINA

National prospective capacity overview

In December 2020, President Xi Jinping introduced a commitment to build over 1,200 GW of solar and wind power by 2030 and to achieve 25% non-fossil fuel usage in its primary energy by 2030. In practice, meeting the 25% target requires much more than 1,200 GW of wind and solar. Nonetheless, this was a crucial move toward achieving China's "dual carbon" commitment, which aims to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060.

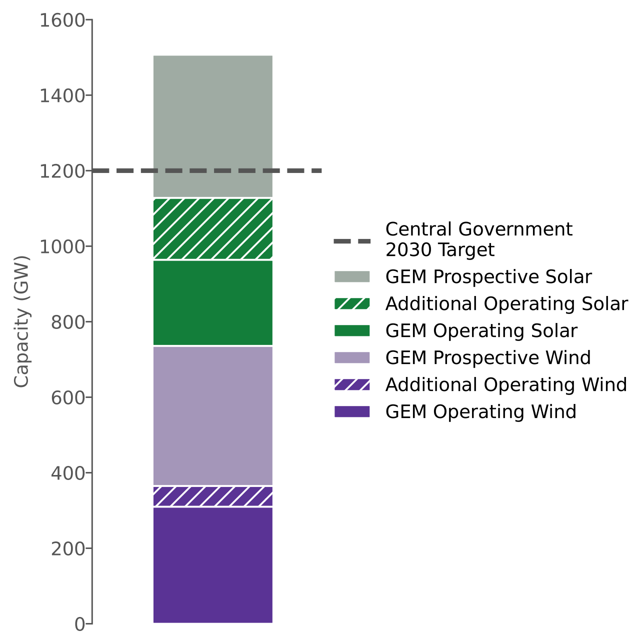
To achieve these goals, both the central government and provincial governments have mapped out ambitious solar and wind targets for the 14th Five-Year Plan. The national 14th Five-Year Plan has reasserted China's dedication to achieving its renewable energy targets by ramping up the deployment of solar and wind projects, while provincial governments throughout the country have established more specific and ambitious targets for wind and solar[6] energy, aiming to achieve them by 2025. Combining the actual targets released by most provinces with estimates[7] for provinces with vague or undisclosed targets, the cumulative provincial wind and solar targets, across all thresholds, amount to approximately 1,371 GW by 2025, as shown in Table 1 (on the next page).

As of the first quarter of 2023, GEM has identified approximately 371 GW of prospective wind capacity and 379 GW of prospective large utility-scale solar capacity. These figures are continuously growing as new projects are announced and publicized. China has demonstrated a track record of surpassing its renewable energy development goals in the previous three Five-Year Plans (11th FYP, 12th FYP, and 13th FYP).

Given this history and the commitment to meet the "dual carbon" targets, the announced projects are highly likely to be successfully implemented.

If all prospective projects are built and commissioned as planned, in addition to the already operating capacity that GEM has identified (large utility-scale solar 228 GW, wind 310 GW) China will likely achieve and potentially surpass its 2030 target of 1,200 GW of cumulative wind and solar capacity five years ahead of schedule.[8]

Figure 4: China's operating and forecasted solar and wind capacity in relation to its 2030 Central Government Target[9]



6. The provincial targets for solar energy encompass cumulative capacity across all sizes and scales, from large-scale down to rooftop installations.
7. For further details please see our Methodology Page.
8. Because GEM only tracks projects that meet a capacity threshold of 20 MW, the total amount of all scales of solar installed by 2025, should all large utility-scale projects come to fruition, will be significantly larger than what has been identified by GEM.
9. For further details on this figure please see our Methodology Page.

Table 1: Wind and solar capacity in China: Operating capacity, prospective capacity, and 14th Five Year Plan targets, listed alphabetically by province[10, 11]

Province	Solar Operating Capacity (MW)[12]	Solar Prospective Capacity (MW)[12]	China 14th FYP Cumulative Solar Target[13]	Wind Operating Capacity (MW)	Wind Prospective Capacity (MW)	China 14th FYP Cumulative Wind Target (MW)
China	**227,761**	**378,622**	**771,551**	**310,274**	**371,075**	**599,080**
Anhui	9,956	7,692	28,000	4,306	5,273	8000
Beijing	51	20	2,510	236	0	300
Chongqing	425	400	1,850	1,093	750	1850
Fujian	451	45	5,000	7,085	6,068	9000
Gansu	11,364	20,393	41,690	18,377	20,746	38530
Guangdong	11,677	16,532	28,000	13,580	37,413	32000
Guangxi	7,241	19,603	15,000	7,286	28,817	24500
Guizhou	11,492	14,885	31,000	4,777	12,173	10800
Hainan	1,105	100	7,458	248	6,900	12300
Hebei	16,018	28,314	54,000	22,910	12,631	43000
Heilongjiang	3,614	2,765	10,500	8,540	9,640	19000
Henan	4,477	2,590	33,330	12,282	13,274	27000
Hubei	11,287	5,738	22,000	5,707	3,898	10000
Hunan	2,791	26,110	13,000	7,862	23,460	12000
Inner Mongolia	14,569	34,214	45,000	40,584	69,653	89000
Jiangsu	5,731	7,556	35,000	19,519	3,209	28000
Jiangxi	6,326	9,081	24,000	4,314	1,774	7000
Jilin	3,131	1,031	8,000	8,830	8,667	22000
Liaoning	2,145	3,869	10,000	10,469	17,744	17800
Ningxia	15,087	20,925	32,500	11,824	6,351	17500
Qinghai	15,488	19,915	45,800	7,228	4,672	16500
Shaanxi	12,810	18,963	31,962	7,564	8,414	25000
Shandong	9,685	33,088	57,000	21,528	6,736	25000
Shanghai	132	44	4,648	1,048	1,106	2600
Shanxi	18,829	13,900	50,000	18,776	7,915	30000
Sichuan	2,225	1,540	10,000	5,085	3,734	10000
Tianjin	1,241	8,315	5,600	1,313	5,278	2000
Tibet	1,385	70	10,000	72	150	Not Found
Xinjiang	17,098	56,422	33,540	22,908	31,640	52000
Yunnan	3,730	3,121	47,163	10,883	7,969	Not Found
Zhejiang	6,203	1,381	28,000	4,042	5,022	6400

10. For further details and references on this table please see our Methodology Page.

11. The provincial targets for solar and wind energy are from official sources where available. Provincial targets highlighted in orange color were estimated where official provincial targets were unavailable or unspecified. For further details please see our Methodology Page.

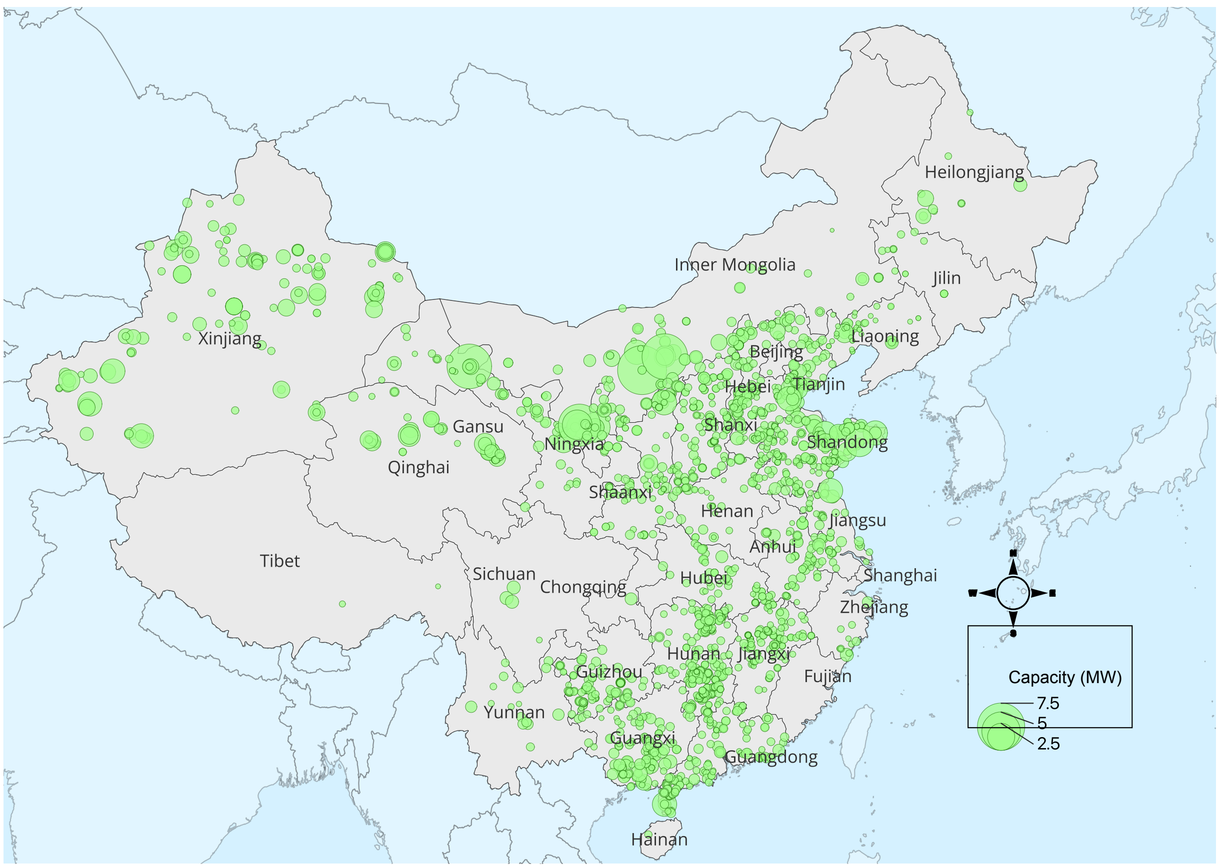
12. GEM's solar capacity values are from large utility-scale projects and do not include any capacities from installations below 20 MW.

13. The provincial targets for solar energy encompass cumulative capacity across all sizes and scales, from large-scale down to rooftop installations.

Solar surge: Leading the way to 1,200 GW

Solar energy is expected to play a leading role in achieving the 2030 target of 1,200 GW of solar and wind power, as about 772 GW of combined cumulative capacity targets have been announced by China's provincial governments (see Table 1).[14] As of 2022, China has achieved a cumulative capacity of about 392 GW of solar energy at all scales from rooftop to large-scale utility. This means that about 380 GW of solar capacity needs to be installed in order to reach the combined target. With 379 GW of prospective large-scale utility capacity identified by the Global Solar Power Tracker, if distributed and small-scale utility installations keep pace with the larger projects, the provincial governments are poised to far exceed their targets. 379 GW represents three times the prospective capacity of the United States and 1.7 times the prospective capacity of all of Europe. The majority of large utility-scale solar farms are situated in the northern regions of China (Map 3).

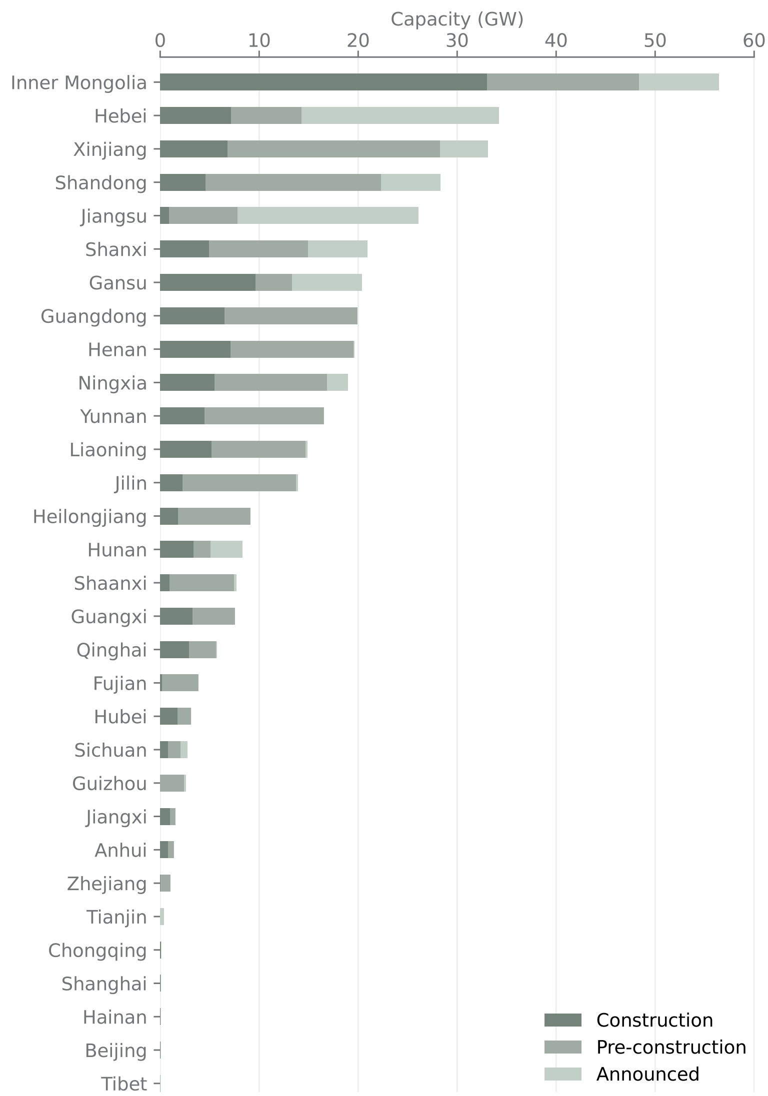
Map 3: Prospective large utility-scale solar capacity in China



14. The provincial targets for solar energy encompass cumulative capacity across all sizes and scales, from large-scale down to rooftop installations.

The top three provinces with the largest pipeline of prospective large utility-scale solar capacity are Xinjiang, Inner Mongolia, and Shandong, with over 56 GW, 34 GW, and 33 GW respectively. Hebei province, which ranks as one of the top players in terms of operating solar capacity, has lined up over 28 GW of prospective large utility-scale solar projects, securing the fourth position. While most of the solar farms in Hunan are relatively smaller compared to those in the northern regions, it is noteworthy that, according to the Global Solar Power Tracker, Hunan has the largest number of large utility-scale solar farms to be developed during the 14th Five-Year Plan period, making it one of the top five players in terms of prospective large utility-scale solar capacity (see Figure 5).

Figure 5: Prospective large utility-scale solar capacity by province/status (construction, pre-construction, announced)



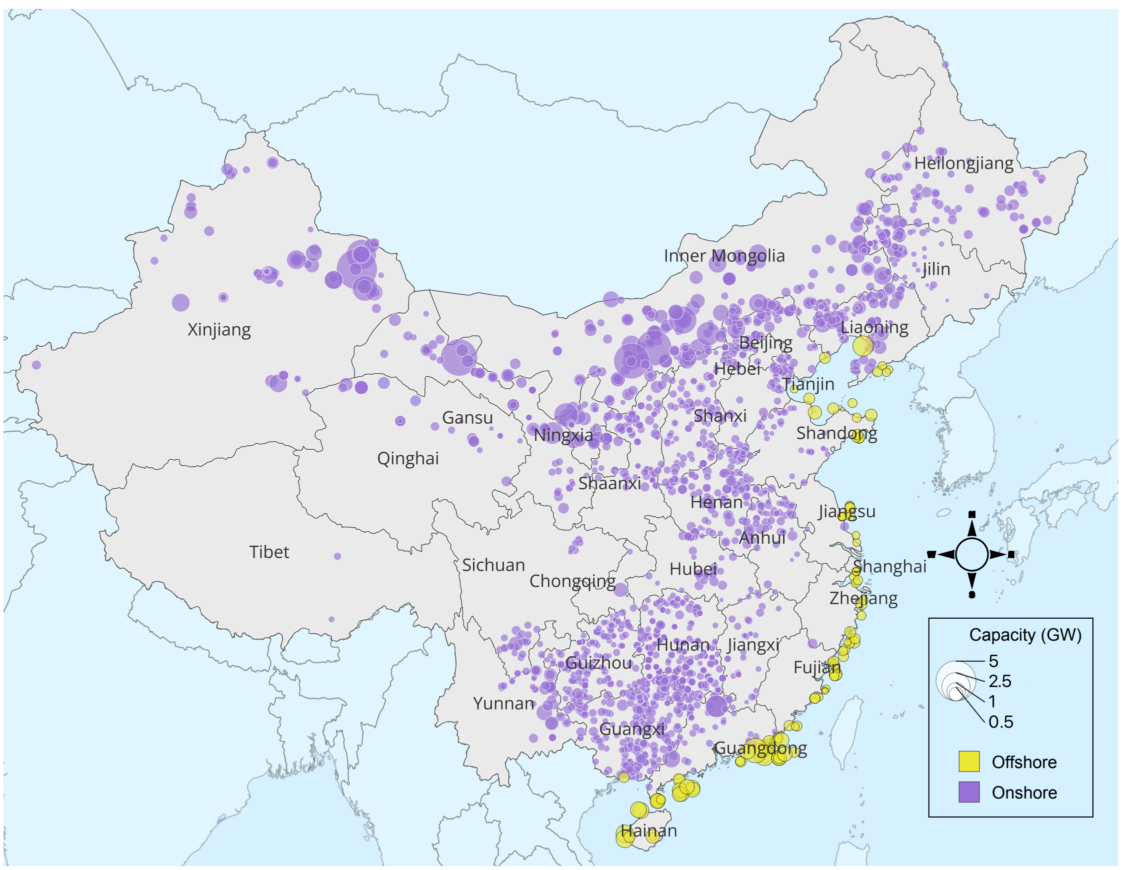
Surpassing the target: China's prospective wind capacity outpaces 14th FYP goals

Provincial 14th FYP wind capacity targets amount to approximately 599 GW (see Table 1). As of 2022, the operating capacity of wind energy in China was approximately 365 GW, including all levels of capacity. This means that an additional 234 GW of wind capacity needs to be installed in order to reach the target. As of now, the operating capacity of wind energy in China, as recorded by GEM, has reached approximately 310 GW, resulting in a gap of approximately 289 GW to reach the provincial target. However, the prospective capacity identified by the Global Wind Power Tracker (372 GW) as of the first quarter of 2023 already exceeds this amount by 29%.

According to Global Energy Monitor wind data, approximately 311 GW of prospective onshore wind and around 60.5 GW of prospective offshore wind capacity are scheduled to come online before 2025 and 2030. While these prospective projects will be distributed throughout the country, onshore wind installations are anticipated to be predominantly situated in the northern and northwestern regions, including Inner Mongolia, Xinjiang, and Gansu, while offshore wind farms are expected to be located along the east and southeast coastal areas, such as Guangdong, Zhejiang, and Hainan (see Map 4).

In the onshore wind power sector, Inner Mongolia is forecasted to maintain its current lead, with almost 70 GW of prospective capacity in the pipeline. This can be attributed to the mega wind and solar bases under construction and development in this region.

Map 4: Prospective wind farm capacity in China



Xinjiang, which has set the highest 2025 renewable energy target among China's provinces, ranks second in terms of prospective onshore wind capacity, with plans to add approximately 32 GW of onshore wind farms. Guangxi ranks third, with plans to add more than 29 GW of onshore wind capacity.

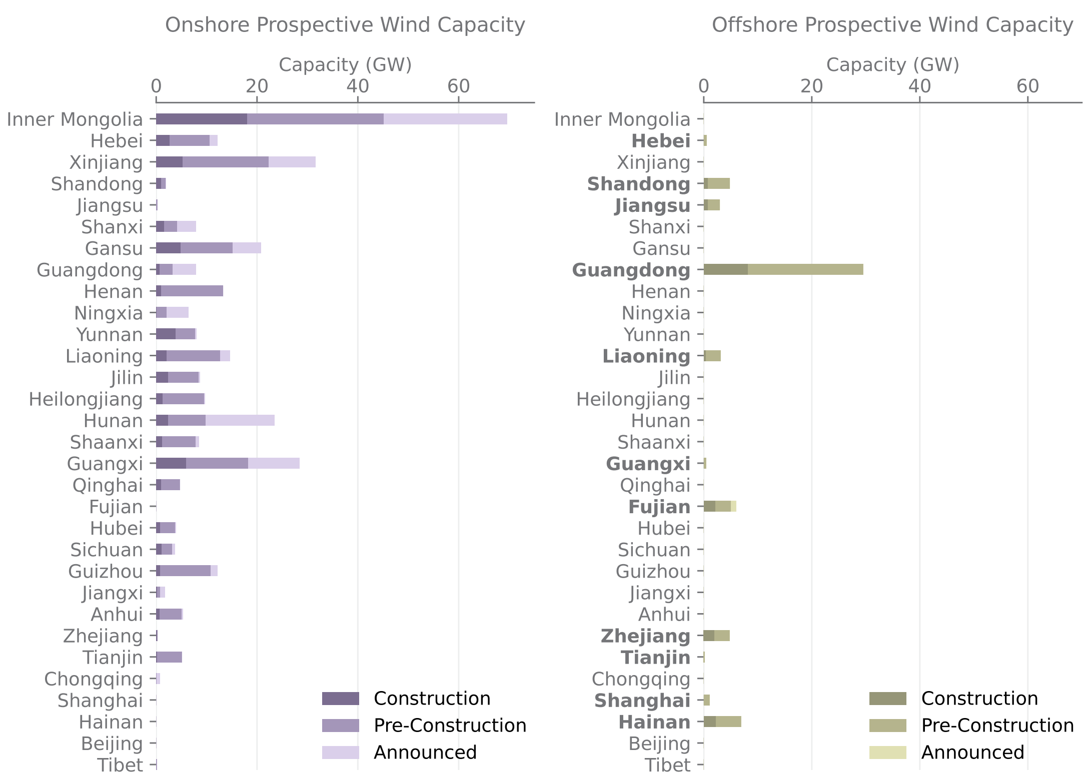
China's offshore wind power sector is set to maintain its strong momentum. Of China's coastal provinces (see Map 4), Guangdong leads with approximately 30 GW of prospective offshore wind farms. Hainan ranks second with approximately 7 GW of prospective offshore wind capacity.

During the 14th Five-Year Plan period, the provinces of Fujian, Shandong, Zhejiang, and Jiangsu have been designated as the four emerging offshore wind power bases, with prospective capacities of 6 GW, 4.9 GW, 4.8 GW, and 3 GW of offshore wind, respectively (see Figure 6).

China's mega wind and solar bases

While continuing to promote renewables development even in parts of the country where wind and solar resources are more marginal, the Chinese central government is making the large-scale development of concentrated "mega wind and solar bases"[15] located in arid regions of Inner Mongolia and Northwest China—with the country's richest wind and solar resources—the focal point of its medium-term

Figure 6: Prospective onshore and offshore wind capacity by province/status (construction, pre-construction, announced)



15. The "mega wind and solar bases" in China refer to designated areas primarily located in sandy and rocky deserts and barren lands with favorable natural conditions, such as vast open spaces, abundant wind resources, or high solar radiation. These bases are characterized by the simultaneous construction of multiple large-scale wind and solar parks, with each park individually capable of generating gigawatts of power. They leverage the vast expanse of available land and favorable environmental conditions in these regions to accommodate the extensive deployment of wind turbines and solar panels. Additionally, supporting infrastructure, such as long-distance transmission lines, is often built to efficiently deliver the generated electricity from these bases to demand centers.

renewables strategy. These developments will play a critical role in driving the necessary growth to meet the country's wind and solar targets.

The first wave of these bases, totaling 97 GW (60.7 GW in the northwest and Inner Mongolia) was announced by the National Development and Reform Commission (NDRC) in December 2021, with a target completion date of 2022–2023. The Global Wind Power Tracker and Global Solar Power Tracker indicate that the bulk of this first group of bases is proceeding as planned and that they are likely to be completed by or soon after the target year-end 2023 deadline.

Typical examples of these bases include the 2 GW Kubuqi desert control photovoltaic complex in Inner Mongolia; the 1.5 GW of wind (four sub-projects), 3.5 GW of photovoltaic (eight sub-projects), and 300 MW of solar thermal (three sub-projects) in Qinghai Province designed to transmit electricity via a long-distance transmission line to southern Henan province; and 2.2 GW photovoltaic (seven sub-projects) and 800 MW wind (three sub-projects) in northern Shaanxi Province to feed a 660 km transmission line to southern Hebei Province.

The NDRC announced a second wave of much larger magnitude in February 2022. This second wave called for new wind and solar mega bases "with Gobi and Wasteland areas as the focal point" totaling 455 GW to be completed by 2030, including 200 GW in the 14th Five-Year plan 2021–2025, and 255 in the 15th Five-Year plan 2026–2030. The four desert areas of Kubuqi, Wulanbuhe, Tenggeli (Tengeer), and Badanjilin, located in Inner Mongolia, Ningxia, and Gansu, are designated to build 258 GW of this amount, more than two thirds of which is planned for shipment via long-distance transmission lines to eastern load centers, with the remainder for local use.

In contrast to most previous base projects where small sub-projects were parceled out among different developers, the central government plans for the largest, most financially secure of the state-owned generation utilities to take on 10 GW or larger projects. Thus far, awards have been announced as per Table 2 below.

Preliminary indications are that achieving at least the 2025 portion of this second wave on time could prove challenging. As of early 2023, the only publicized ongoing construction in conjunction with any of the four core desert bases (original target 128 GW by 2025) consisted of one GW's worth of PV components for the North Kubuqi and Tenggeli Desert Ningxia developments. The others all appear to be in the feasibility study or permitting stage.

Table 2: Renewables desert megabases in northwest China

Renewables Base	Developer	Wind Capacity	Solar Capacity	Total Capacity
North Kubuqi Desert Renewables Base, Inner Mongolia	China Three Gorges Group	4 GW	8 GW	12 GW
South Kubuqi Desert Renewables Base, Inner Mongolia	China Huaneng Group	4 GW	8 GW	12 GW
Tenggeli Desert Renewables Base Southeast, Ningxia	China Energy Investment Group	1.8 GW	9 GW	11 GW
Tenggeli Desert Renewables Base, Inner Mongolia	China Huadian Group	4 GW	8.8 GW	12.8 GW
Tenggeli Desert Renewables Base, Gansu	Gansu Power Investment Group	NA	NA	6 GW
Badanjilin Desert Renewables Base, Gansu	China Energy Investment Group	4.3 GW	6.7 GW	11 GW
Badanjilin Desert Renewables Base, Gansu	Gansu Power Investment Group	NA	NA	6 GW

4. DRIVING FORCES BEHIND CHINA'S SUCCESSFUL WIND AND LARGE UTILITY-SCALE SOLAR DEVELOPMENT

China's remarkable build-out of wind and solar energy throughout the country can be attributed above all else to the central priority China's government has attached to renewables development over the past fifteen years. Namely, the government has implemented a full range of policies and incentives to both encourage and pressure stakeholders to produce and consume renewable energy. It has also ensured financing not just for the plants themselves, but also for the supply chain and construction infrastructure necessary to build them. By taking advantage of this funding and of the immense domestic market opportunities, China's suppliers have relentlessly driven down costs, making renewables development economically competitive and sustainable while achieving dominance as the largest global supplier of solar panels as well as one of the leading manufacturers of wind turbine components.

Key incentives propelling large utility-scale solar and wind build-out

The Chinese government policies fueling the renewables construction boom can be divided into those that incentivized developers to build, and those that pressured them to do so. Until 2021, generous feed-in tariff subsidies for both wind and solar was one of the key measures of the first type.

In 2009, the government fixed onshore wind plant tariffs at 0.51–0.61 yuan/kWh, depending on the quality of the wind resources, a premium of approximately 67–100% over the then-prevailing average coal power plant offtake tariff. Photovoltaic subsidies began in 2011, with offtake tariffs fixed at 1 yuan/kWh, more than three times the prevailing coal power price.

The subsidies were reduced in stages over the past decade as renewables investment costs dropped, and were abolished for most new wind and solar projects starting in 2021. However, some provincial governments have announced continued investment or feed-in tariff subsidies for offshore wind projects coming onstream through 2023, with some committing to 2026 due to these projects' continued high costs.

Moving forward, it is possible that wind and solar plants will be able to generate extra revenue through the sale of "green certificates" to downstream users under pressure to meet renewables purchase quotas. The national government has both made major efforts to ensure that renewables projects receive favorable dispatch, as well as protected their revenue by tying offtake tariffs for a portion of their output to government benchmark coal power tariffs at a time when new renewables facilities are cost competitive with coal power.

Favorable taxation policies for renewables power have been another incentive for investors. In 2008, the central government entitled wind power plant owners to a 50% rebate of the then 17% (now 13%) Value Added Tax on power sales, a privilege extended later to solar power plants. A 2009 regulation exempts renewables owners from income tax entirely during the first three years of operation, and reduces the otherwise 25% rate by half for years 4–6.

Finally, the government has ensured a plentiful flow of financing on favorable terms to wind and solar developers. Since 2009 at least, the major state-owned banks have made 15-year loans available to renewable energy developers. Under the carbon emission reduction loan program announced in 2021, which allows the big state-owned commercial banks to obtain funds from the Chinese central bank on highly favorable terms, wind and solar developers have been obtaining loans at 3.85% interest. Over the years, China has provided cumulative loans for wind and solar projects of over US $250 billion.

Mandates and regulations incentivizing large utility-scale solar and wind development

In addition to offering incentives, the Chinese government also fixes requirements and applies pressure on both generating companies and provincial governments to meet renewable energy targets.

National plans and campaigns to build large renewables bases, launched in coordination with provinces eager to obtain investment, are themselves a type of pressure on the state-owned generators to participate, which they inevitably do. Large generating companies have been required to meet specific renewables targets such as minimum 9% of power generation from renewables by 2020, and there has been discussion of tying generation of renewable energy alongside their fossil power to the ability of coal-fired power plants to get favorable dispatch.

To date, the most important mandatory measure to induce large utility-scale solar and wind deployment consists of an annual set of province-level minimum targets for percentage of total electricity consumption from non-hydro renewables. The central government audits the provincial performance in detail, with purchase of "green certificates" issued by renewables generators an important basis for verification of provincial end users' actual renewable energy use.

On a national basis, wind and solar accounted for 11.5% of national electricity production and consumption in 2021 and 13.4% in 2022. All provinces except Xinjiang met their non-hydro renewables electricity utilization targets in 2021, with many exceeding them by margins ranging from 0.5–4.4 percentage points. In 2022, the central government raised the targets by 1–2 percentage points, suggesting a built-in expectation for provinces to overperform. If the increase in wind and solar of the past two years can be sustained, China should achieve its target of 25.9% non-hydro renewable electricity consumption by 2030.

Clean energy raw material supply chain dominance is key to China's success

China's dominance in the global renewable energy supply chain, and particularly in wind and solar development, is central to the country's wind and solar take-off.

The country's global share in every stage of solar power manufacturing, including polysilicon, ingots, wafers, cells, and modules, surpasses 80%, thanks to many years of government policies as well as investment aimed at developing a robust domestic industry. The 10th Five-Year Plan (2001–2005) set the stage for the scaling up of solar PV cell and module manufacturing, while during the 11th Five-Year Plan (2006–2010), the promotion of domestic polysilicon and equipment manufacturing was emphasized. Since 2011, China has invested more than $50 billion in new PV supply capacity, ten times the amount invested in Europe over the same period and created more than 300,000 manufacturing jobs across the solar PV value chain, according to the IEA.

China's wind turbine manufacturing industry has likewise come to dominate the global market, with seven of the top ten wind turbine manufacturers being Chinese companies. Prior to 2005, China depended entirely on imported wind blades. However, in 2005, the National Development and Reform Commission issued a notice mandating that all wind farms source at least 70% of their equipment domestically. Consequently, by 2009, domestically made components met more than 85% of China's market demand.

Furthermore, China dominates the processing and refining operations of some key wind turbine minerals, particularly rare earth elements (REEs), thereby further strengthening China's position as the primary base for wind turbine component manufacturing. With China accounting for 60% of global output in REEs, which are essential for the permanent magnets that power turbine generators, the country has secured a reliable supply of these critical materials and reduced its dependence on other countries for raw materials. Since 2013, the market share of domestically manufactured wind generating units has remained above 95%.

In addition to the aforementioned incentives, regulations, and centrally managed investments that have catapulted China to the top of the world's wind and solar race, the country's large utility-scale solar and wind rollout dynamics have been further characterized by particular initiatives that have encouraged uptake. These include a persistent focus on establishing offshore wind power bases, investment in long-distance transmission infrastructure, the Solar Energy Poverty Alleviation Program (SEPAP), and the Frontrunner Photovoltaic Program (FPP).

Leading the global offshore wind boom

China leads the world in offshore wind capacity because the central government has consistently made it a priority to do so. According to the Global Wind Power Tracker, China's offshore wind represents approximately 10% of total operating and close to 20% of total prospective wind capacity. While offshore wind farms globally boast higher capacity factors than their onshore counterparts, China's offshore wind bases have the added benefit of being located in close proximity to the country's largest load centers in the coastal provinces.

As in other countries, due to its higher cost and greater technical complexity, offshore wind development began later in China than onshore. However, by 2010–2011 the central government mobilized the coastal provinces to draft offshore development plans for the near-in waters they manage (further out waters are under national control) and established a regulatory framework for project development, environmental evaluation, and approval.

Jiangsu Province, which lies adjacent to extensive areas of shallow water in the Yellow Sea north of the Yangzi River delta, was the first to respond with a 15-year offshore development plan. The central government supported Jiangsu's efforts by mobilizing four concession projects there (1 GW aggregate) through competitive bidding in 2010. As a result, Jiangsu province commissioned over 5 GW of offshore wind capacity by 2020, close to two-thirds of the national total. By the end of 2021, the total had jumped to 11.3 GW, well surpassing the original 15-year plan target.

Guangdong in the south, with approximately 68 GW of potential in provincially administered waters, was the second to move in a major way. After a false start in the early 2010s as the various marine interests sorted themselves out, it has steadily implemented a revised offshore plan for 2017–2030, calling for the installation of 30 GW in the South China Sea, with 8.4 GW already in operation as of the first half of 2023.

With the exception of Guangxi Province bordering Vietnam and the island province of Hainan in the South China Sea, all the remaining coastal provinces now have operating offshore wind farms run by national or provincial government-owned generation utilities. They extend as far as 85 km offshore, and for the most part are located in so-called "shallow" waters of less than 35 meters depth. In Guangdong, systematic development in 35–50 meter depth has begun. Planned capacity factors for the shallow water projects range from as low as 26% in western Guangdong to as high as 40-45% in or near the Taiwan Straits off of eastern Guangdong and Fujian.

All eastern and southern coastal provinces have now launched large-scale offshore wind construction programs (Figure 4). Fujian, Zhejiang, Shandong, and Jiangsu are planning to add 6 GW, 4.9 GW, 4.8 GW, and 3 GW respectively during the 14th Five-Year Plan period, in addition to the 30 GW that Guangdong is planning to commission by 2030. The central government is also developing a plan for the "further out" offshore waters for which it is responsible. Hainan Island, China's "tropical paradise" for which the GEM tracker has identified prospective projects totalling 7 GW, faces special conditions. Environmental concerns within the provincial political leadership put its plans temporarily on hold from 2018 to 2021, and its ability to absorb such a large increment of new power may depend on the construction of a second subsea transmission line between the island and Guangdong, or on the development of a downstream industrial infrastructure such as green hydrogen specially geared towards renewable energy.

— A CASE STUDY —

INVESTING IN LONG-DISTANCE POWER TRANSMISSION INFRASTRUCTURE: THE HAMI (XINJIANG)–ZHENGZHOU (HENAN) TRANSMISSION LINE

Both China's coal and renewables resources are disproportionately concentrated in the relatively sparsely populated, light-load northwest. To get this energy to market, the government has completed 12 ultra-high-voltage long distance transmission lines to ship a combination of coal and renewables power from the northwest to the more populated, high-GDP but energy-deficient areas further east.

One of them, the 2,190 km long, 800 kV Hami (Xinjiang)–Zhengzhou (Henan) high voltage direct current (HVDC) transmission line with its associated upstream generation facilities serves as a prototype for supporting the massive northwestern renewables bases planned for the years to come. Completed in 2014, Hami–Zhengzhou was among the lines for which renewables figured most prominently from the beginning, yet, like other similar projects, always in close conjunction with coal power.

In 2013, the central government approved construction of 8 GW of wind and 1.25 GW of photovoltaic capacity to feed this line. Simultaneous with the renewables facilities, state-owned generation companies commissioned three new coal power plants with aggregate 5.3 GW capacity in 2015–2016 and an additional 1.3 GW in 2019–2020 for the transmission line, under the auspices of compensating for the intermittency of wind and solar power. This 1.4:1 renewables to coal capacity ratio represented a slight loosening of a previous informal standard for the grid company which called for a maximum capacity ratio of 1.1:1 to ensure grid stability.

In 2020, the Hami–Zhengzhou line shipped 40.9 TWh of power, of which 40.7% was from the renewables plants (implied capacity factor 23.4%), with the remaining 59.3% from the coal plants (implied 52.4% capacity factor). Power shipments over the line increased to 44.6 TWh in 2021, but as the new increment consisted solely of coal power (possibly a result of the new coal-fired plant coming onstream in the previous year), the renewables portion dropped to 35.8%. With a reported line power shipment capacity of 8 GW, there remains room for further growth.

— A CASE STUDY —

THE SOLAR ENERGY POVERTY ALLEVIATION PROGRAM: THE NINGXIA YANCHI ZHONGMINTOU POVERTY ALLEVIATION SOLAR FARM

Recognizing the potential of renewable energy in addressing poverty in some of its impoverished areas, the NEA and the State Council jointly issued a work plan to implement the Solar Energy Poverty Alleviation Program (SEPAP) in 2014. The six-year program aimed to install over 10 GW of capacity and benefit more than two million households from around 35,000 villages across the country by 2020. The program supported high-poverty counties and rural villages primarily through small-scale solar projects, typically ranging from 100 kW to 300 kW.

Despite this emphasis on smaller-scale projects, some large-scale projects with a capacity of over 10 MW, such as the Ningxia Yanchi Zhongmintou Poverty Alleviation solar farm, were also built through this program. Developed by the China Minsheng Investment Group in 2018, the Ningxia Yanchi Zhongmintou Poverty Alleviation solar farm is one of the largest-scale SEPAP projects recorded in the Global Solar Power Tracker. This project spans 74 impoverished villages in Yanchi County of Ningxia with a total capacity of 234 MW, and benefits 9,146 rural households.

In 2020, the SEPAP program was fully completed, installing a total of 26.36 GW of solar energy poverty alleviation stations across the country. The majority of the projects were distributed and small-scale, with only around 5.6 GW of solar farms related to the SEPAP initiative meeting the inclusion criteria for the Global Solar Power Tracker.

— A CASE STUDY —

THE FRONTRUNNER PHOTOVOLTAIC PROGRAM: THE SHANXI DATONG COAL SUBSIDENCE AREA FRONTRUNNER DEMONSTRATION BASE

The Frontrunner Photovoltaic Program (FPP) was proposed by the National Energy Administration in 2015 to advance the development of photovoltaic technology, reduce construction costs and on-grid electricity prices, and promote industry-wide advancement. The FPP initiative involved two types of demonstration bases: application-leading and technology-leading. From 2015 to 2017, the Chinese government issued three batches of FPP projects, totaling approximately 14 GW of installations across 10 provinces, mainly in the northern parts of the country, which are abundant in solar energy resources.

One of the FPP demonstration bases is the Shanxi Datong Coal Subsidence Area Frontrunner Demo Base, endorsed by the NEA in 2015. Datong, a city primarily dependent on coal resources, recorded a subsidence area of 1,687 square kilometers due to extensive and long-term coal mining. The demonstration base utilized abandoned land in the coal mining subsidence region to construct a 1 GW photovoltaic power station, composed of seven 100 MW projects and six 50 MW projects.

In order to participate in the FPP initiative, domestic PV suppliers must adhere to high standards of performance, with polycrystalline modules required to have a conversion efficiency of at least 16.5% and monocrystalline modules at least 17%. This approach has prompted Chinese manufacturers to shift their focus from multicrystalline to more efficient monocrystalline technology. As some leading enterprises become industry benchmarks, other enterprises in the industry have been driven to improve product quality and conversion efficiency, thereby promoting competition and development of the entire industry.

Figure 7: A satellite picture of the Shanxi Datong Coal Subsidence Area Frontrunner Demonstration Base

Imagery ©2023 CNES / Airbus, Landsat / Copernicus, Maxar Technologies, Map data ©2023

5. LOOKING AHEAD: FUTURE TRENDS AND DEVELOPMENTS

Emerging trends in the Chinese wind and solar sectors include source-grid-load-storage integration, the integration of coal with renewables, energy storage, and green hydrogen. With these developments, China aims to optimize the performance of renewable energy sources while tackling the intermittent and volatile nature of wind and solar power.

Source-grid-load-storage integration projects and multi-energy complementarity

The Chinese government is promoting the integration of source, grid, load, and storage, as well as multi-energy complementarity to optimize the country's energy system and promote efficient energy resource use during the country's 14th Five-Year Plan period. This emphasis is in response to the challenges posed by the intermittent and volatile nature of wind and solar power, which have become a larger portion of the energy mix. Currently, the Global Solar and Global Wind Power Trackers include over 27 GW of source-grid-load-storage integration projects and over 17 GW of multi-energy complementarity projects. These projects are mainly large-scale and concentrated in the northern regions and their expected completion date is generally no later than 2025.

The source-grid-load-storage integration approach involves coordinating the generation, transmission, distribution, and storage of electricity in an energy system. There are two types of source-grid-load-storage integration projects:

- Small-scale projects, which target power consumption issues for small entities such as industrial and commercial parks, residential areas, complexes, and hospitals;
- Large-scale projects, referred to as energy base projects, which primarily use energy storage technology to deal with the seasonal and fluctuating characteristics of wind and solar.

The source-grid-load-storage integration approach is still a relatively new model, and the majority of projects in this category are sourced from the data list released by local governments, with many of them being classified as pilot projects.

Multi-energy complementarity is another approach that optimizes energy generation, distribution, and consumption by utilizing multiple energy sources in a complementary manner. It involves combining various energy sources, including renewables like solar, wind, and hydro, and conventional sources like coal to create an energy system that is more efficient and stable.

In China, multi-energy complementarity takes different forms, such as hybrid systems that integrate renewable and conventional energy sources, or systems that combine different energy sources with storage technologies. For example, coal is used as a so-called "pillar of support" energy source, ostensibly to ensure stability in the energy system.

Integrating coal with wind and solar power

Despite China's undisputed leadership in large utility-scale solar and wind deployment, in 2022, fossil fuel power plants nevertheless generated two thirds of China's electricity. Thus, the key issue for China's energy transition remains how, and over what time frame, renewables will replace coal, the country's primary fossil fuel. The Global Wind and Solar Power Trackers suggest several paradigms for how coal and renewables are being integrated.

One such paradigm is for existing large coal plants serving distant markets to begin adding utility-scale wind and solar capacity. These hybrid power stations would operate as one complex and ship electricity over the shared coal/solar/wind long-distance transmission lines, ostensibly triggering an incremental reduction in coal power generation. Existing coal plants throughout Inner Mongolia and the northwest are pursuing this paradigm, possibly incentivized to obtain the "green certificates" associated with renewables generation.

One representative example is the so-called "Daihai Wind/Solar/Thermal/Storage/Hydrogen Complex" in Inner Mongolia. The 2.4 GW Daihai coal power plant has shipped power 350 km through a dedicated transmission line to Beijing since 2005. The first stage of its transformation into the "integrated complex" consists of the addition of 1,500 MW of wind capacity in the vicinity designed to produce 3.628 billion kWh per year, about 25% of Daihai's maximum output as a base-loaded plant, but close to one third of its output in more recent, pandemic-influenced years.

A second paradigm is the integration of new coal capacity into the new renewables bases in the northwest as so-called "pillars of support" to ensure consistent power supply. The proportion of new renewables *capacity* to coal capacity in these new bases, at 2:1 or 3:1, is significantly higher than in earlier projects such as the Hami–Zhengzhou transmission line discussed above.

Projected power *generation*, however, tells a different story. The Chinese State Council in October 2021 stipulated that the transmission lines from these bases to load centers should ship "at least" 50% renewables power, and the preliminary evidence from the examples in Table 3 below suggests that the planned renewables share of shipments from the bases is about 55% in most cases, with new coal plants making up the remaining 45%. As back-up to renewables plants, furthermore, the coal plants will be required on occasion to operate at lower loads and with more rapid ramp-up and ramp-down rates than have traditionally been considered normal, using technology which China and other countries have demonstrated to be feasible, but which could result in higher coal consumption and CO2 emissions per unit of power, as well as increased wear and tear on the plants themselves.

The data in Table 3 come from Chinese media reports projecting what total shipments along the associated transmission lines will be and what the renewables shipments will be. Coal power plant power shipments are based on media reports that the plants will operate at 5000 hours per year full load equivalent (57% capacity factor); this standard is assumed for cases where the hours have not been announced.

Table 3: Renewables bases and coal[16]

Renewables Base	Associated Transmission Line	Line Details	Coal Capacity	Renewables Capacity	Estimated Coal Generation (% of line total)	Estimated Renewables Generation (% of line total)
Qingyang Wind and Solar Demonstration Project	Gansu to Shandong	800 kV HVDC, 943km	4 GW	8 GW	20 TWh/year (53%)	18 TWh/year (47%)
Hami Renewables Base	Hami to Chongqing	800 kV HVDC 2283 km	4 GW	10.8 GW	20 TWh/year (45%)	24 TWh/year (55%)
North Kubuqi Desert Renewables Base	North Kubuqi Desert to Beijing area	NA	4 GW	12 GW	20 TWh/year (43%)	26 TWh/year (57%)
South Kubuqi Desert Renewables Base	NA	NA	4 GW	12 GW	20 TWh/year (45 %)	24 TWh/year (55 %)
Tenggeli Desert Southeast Renewables Base	Ningxia to Hunan	800 kV HVDC 1487 km	4 GW	13 GW	20 TWh/year (45%)	24 TWh/year (55%)
Tenggeli Desert Inner Mongolia Renewables Base	NA	NA	4 GW	12.2 GW	20 TWh/year (45%)	24 TWh/year (55%)

16. For further details and references on this table please see our Methodology Page.

These projections, of course, are not binding. The coal plants may, in fact, run at fewer than 5,000 hours per year. But the possibility that the big new bases at the center of China's renewables development plans might in fact result in the shipment of close to one kWh of new coal power for every new kWh of renewables power underscores the urgency, from a carbon dioxide emissions perspective, of developing alternative capabilities for balancing out the intermittency of renewables power generation.

Some experts believe that the relative inflexibility of the planned high voltage direct current transmission lines could be a contributing factor to the need to balance renewables power with so much coal power at the bases. Rather than building these lines, which allow shipments in only one direction, with no possibility of connection with points in between the source and final destination, they advocate for more numerous and flexible grid interconnections which would make it possible to take advantage of regional complementaries (for example, between hydro and wind or solar) in ways that require less coal generation. More aggressive demand-side adjustments to renewables variability—perhaps "source-grid-load-storage" projects on a larger scale—is another suggested measure that would work towards this goal. Finally, as outlined below, energy storage of various kinds will play a critical role.

In sum, the gradual transition of coal from a primary source of power to a supporting source being deployed to support renewable energy may potentially hinder the progress of phasing out coal and lead to creation of stranded assets due to overcapacity issues.

Energy storage: A requirement for large utility-scale solar and wind projects

New energy storage is a crucial component of the source-grid-load-storage integration model and a key enabler of a renewable-led system. It facilitates peak-shaving and valley-filling, wherein energy generated during peak wind and solar power generation is stored and released during peak power consumption, resulting in reduced wind and solar curtailment rates as well as reduced need for fossil-fuel based peaker plants.

New energy storage methods include new types of batteries such as lithium-ion and flow batteries, compressed air, flywheel, hydrogen (ammonia) storage, and thermal (cold) storage, excluding pumped hydro, which generates electricity by utilizing water stored behind dams. With the issuance of multiple programmatic documents and detailed government implementation plans during the 14th Five-Year Plan period, the new energy storage industry is expected to experience a surge. Notably, in July 2021, the National Development and Reform Commission and the National Energy Administration jointly released the Guiding Opinions on Accelerating the Development of New Energy Storage, which set a specific target of achieving over 30 GW of new energy storage capacity by 2025 and pledged to realize the full market-oriented development of new energy storage by 2030.

By January 2023, 25 provinces and municipalities have plans to install new energy storage with a total scale of approximately 68 GW during the 14th Five-Year Plan period. The total planned capacity of these regions is nearly twice that of the national plan of 30 GW. Generally, these regions allocate no less than 10% of installed capacity for storage and require a storage duration of more than two hours for all new renewable projects. In certain areas, such as Inner Mongolia, Shandong, Henan, Shaanxi, the allocation and storage requirements for new energy projects even exceed 15% to 20%.

The Global Solar and Global Wind Power Trackers have identified approximately 115 GW of prospective large utility-scale solar and wind projects with storage requirements, with 69 GW from solar projects and 46 GW from wind. Assuming these projects allocate 10% of their installed capacity for storage and have a storage duration of more than two hours, it is estimated that 11.5 GW / 23 GWh of storage capacity will be achieved. However, this estimate is expected to be surpassed as some provinces and cities have not yet disclosed either their storage targets or their new lists of prospective solar and wind projects.

Forging ahead with green hydrogen production

Green hydrogen—made via electrolysis of water powered by wind or solar power—as well as downstream products such as ammonia constitute forms of storage with the potential to compensate for not only short-term fluctuations in renewable energy supply but also for longer-term seasonal fluctuations. While popularization of green hydrogen faces a host of economic and technical challenges, including its explosiveness and susceptibility to leakage, China is already a world leader in nascent green hydrogen technology. The country has commissioned at least seven projects to date powered by approximately 0.5–1 GW of wind and solar farms, the flagship of which is a 14,000 ton per year solar-powered facility in Ningxia Province.

The State Energy Administration's Medium and Long-Term Plan for Hydrogen 2021–2035 calls for China to excel in all stages of hydrogen production including storage, transportation, and utilization. The plan emphasizes that going forward, hydrogen should either be recovered as an industrial by-product, or produced using renewable energy, and that hydrogen from fossil fuels should be very strictly controlled.

Not surprisingly, therefore, the Global Wind and Global Solar Power Trackers show an upsurge in wind and solar projects associated in some way with downstream hydrogen use, with at least 19 GW of combined wind and solar capacity either in construction or under development. In many of these projects, hydrogen production will only use a small fraction of the total electricity production. For example, the Inner Mongolia Chagannaoer Thermal-Wind-Solar-Hydrogen Demonstration Project has a 500 MW capacity that will feed a 10 MW electrolytic hydrogen production facility. However, there are other projects that appear to be mostly or entirely dedicated to hydrogen. In January 2023, Inner Mongolia's provincial authorities announced a series of 15 wind and solar projects with aggregate 11 GW and associated with conditions requiring at least 80% of the capacity be dedicated for hydrogen production.

Despite the *Medium and Long Term Plan for Hydrogen* calling for experimental projects to use hydrogen for the grid to generate power for peaking and load balancing, none of the projects identified by GEM are intended for this use. Rather, for the bulk of the so-called "Wind Solar Hydrogen Storage" complexes in the Global Wind and Solar Power Trackers, the hydrogen is intended for a downstream end-use, such as fuel cell motor vehicles, ammonia, or industrial applications including coal based chemicals. In at least one case, the hydrogen will be shipped long distance by pipeline to an oil refinery.

6. DATA GAPS AND FUTURE RESEARCH

The Global Wind and Global Solar Power Trackers are updated annually. However, due to potential lags or gaps in project-level, publically available data sources, as well as data collection timing compared to data publication date, both trackers may be missing some projects that meet the inclusion criteria. Distributed solar, off-grid installations, and grid-connected utility-scale solar below the Global Solar Power Tracker's 20 MW threshold for inclusion is estimated to represent roughly 42%[17] of China's total operating solar capacity. Globally, solar installations above 1 MW constitute only 56% of all operating solar capacity. Global Energy Monitor is currently evaluating strategies for incorporating <= 20 MW solar data in future dataset releases. Furthermore, while it is rare for wind projects to be below Global Energy Monitor's 10 MW wind threshold, we estimate such projects constitute 5%[18] of global capacity.

17. Comparing GEM's 228 GW of operating capacity in China to the 392 GW of operating capacity published by China at the end of 2022.
18. GEM's global operating wind capacity is 786 GW. IRENA estimates a global total of 898 GW at the end of 2022.