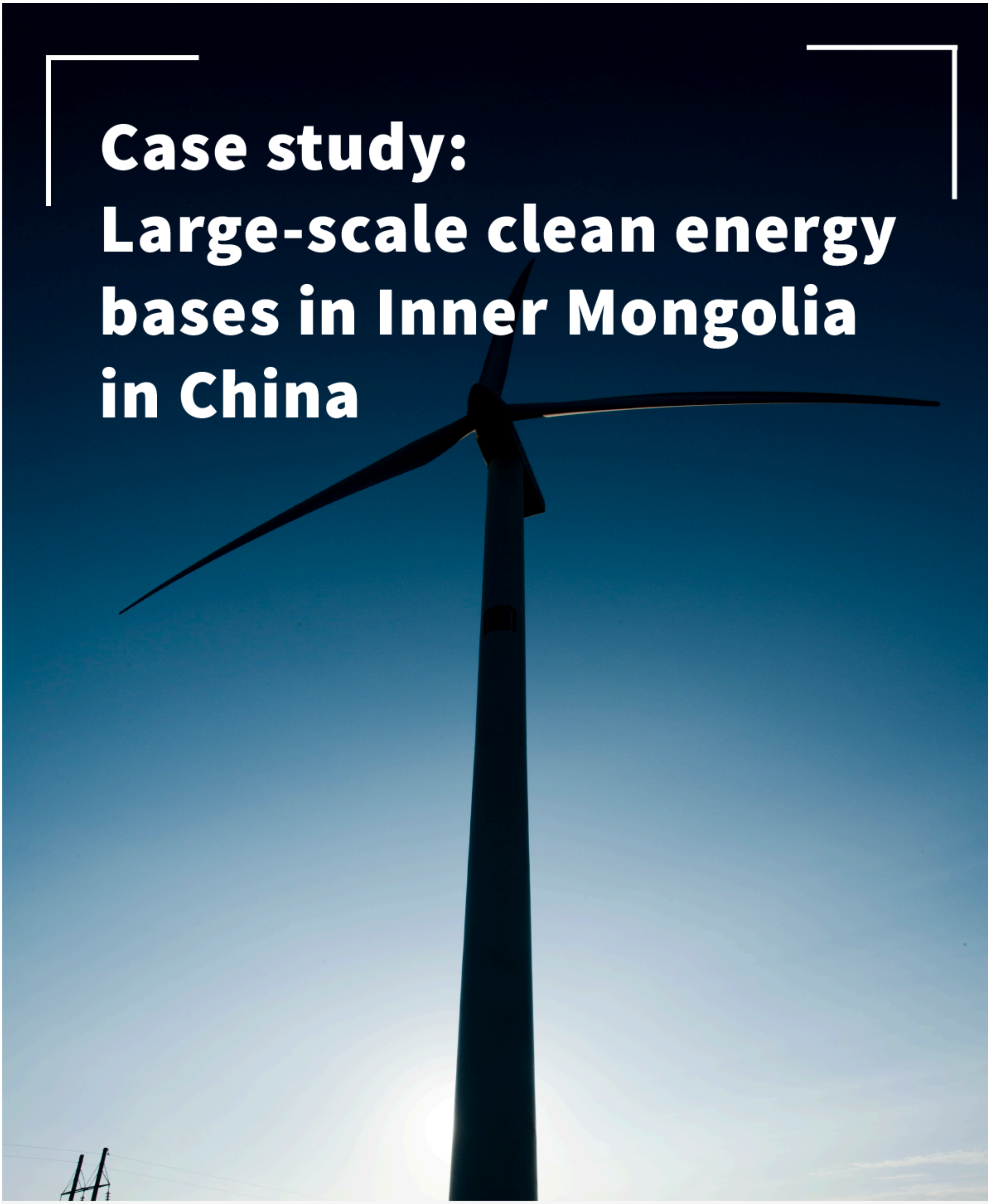
Case study: Large-scale clean energy bases in Inner Mongolia in China



CREA
Centre for Research on Energy and Clean Air

WaterRock Energy Economics

Case study: Large-scale clean energy bases in Inner Mongolia in China

A follow-up case study on '*Resolving near-term power shortages in China from an economic perspective*' , CREA, WaterRock Energy Economics, 2023

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About CREA

The Centre for Research on Energy and Clean Air (CREA) is an independent research organisation focused on revealing the trends, causes, and health impacts, as well as the solutions, to air pollution. CREA uses scientific data, research and evidence to support the efforts of governments, companies and campaigning organisations worldwide in their efforts to move towards clean energy and clean air. We believe that effective research and communication are the keys to successful policies, investment decisions and advocacy efforts. CREA was founded in 2019 in Helsinki, Finland and has staff in several European and Asian countries.

About WaterRock Energy Economics (HK) Ltd

WaterRock Energy Economics provides economic and commercial consulting services on the electricity and gas sector to governments and businesses in Asia. In the past seven years, our clients have engaged us on a wide range of matters ranging from assessing opportunities and risks of investing in renewable, battery energy storage solutions and gas/LNG projects in Asia, to economic analysis and quantitative forecasting for renewable and flexible capacity in Asia and regulatory support on electricity market design in Singapore, the Philippines, Malaysia and China.

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Executive summary

Inner Mongolia has more than 6 terawatts (TW) of exploitable capacity in wind and solar. The region has expansive areas of land and is relatively close to load centres in North, Central and East China. Thus, Inner Mongolia is well positioned to build large-scale renewable energy bases for both local consumption and export to other provinces in China.

Inner Mongolia started to build large-scale wind energy bases between 2007 and 2015. However, those projects faced high curtailment rates in the first few years of operation. **One key lesson that can be derived from this situation is that investment in large-scale clean energy projects in inland provinces needs to link with the development of export transmission infrastructures for exporting to load centres.**

Around 2014, the drivers of China's ultra-high voltage (UHV) system infrastructure development shifted to the practical needs of reducing renewable curtailment rates in inland provinces, ensuring supply adequacy and promoting cleaner air in load centres. All five existing UHV lines out of Inner Mongolia were approved in 2014-2015 and were commissioned in 2016-2018. However, even though the UHV lines have been running for more than five years, **their utilisation rates in Inner Mongolia have been relatively low, at less than 40%. The share of renewable energy in exports has also been low, with three UHV lines at less than 10% and the other two UHV lines at about 30%.** The low utilisation rates of UHV lines are mainly driven by two factors:

- The construction of the UHV lines, associated large-scale clean energy projects, local grid enhancement projects and potential demand from importing provinces are not well aligned.
- Inter-provincial trading arrangements are still relatively rigid and the negotiation of contractual agreements is mainly driven by provincial governments and provincial grid companies between the sending and receiving provinces.

As of September 2024, 27 GW of new clean energy bases are planned and under construction in Inner Mongolia, mainly for exporting to load centres through the existing UHV lines. **Based on our analysis, renewable exports from large-scale clean energy bases in Inner Mongolia to the load centres are more cost competitive than exports from neighbouring inland**

provinces or using local resources in the load centres. They can also help to better utilise existing infrastructure and reduce carbon emissions. Thus, we recommend that the development of these clean energy bases should be pushed forward and accelerated if possible.

Inner Mongolia plans to build four 'Sha-Ge-Huang' clean energy bases. Each clean energy base will have 8 GW solar, 4 GW wind, 4 GW supporting coal and one dedicated UHV DC line. 65%-70% of the electricity generation will be exported to load centres. Based on our analysis, which is presented in Chapter 4.3.2, **we do not expect that 4 GW of new coal power projects will be required by the new clean energy bases to meet their targets.** Detailed technical studies should be carried out to determine how to minimise the amount of new coal capacity for the supporting role.

- **The development of voltage-sourced converter (VSC) HVDC technology in recent years has enabled the movement of bulk variable renewable power from remote resource areas with weak areas of the grid to load centres.** Having coal-fired power capacity to help manage technical stability issues of the transmission line may no longer be needed.
- Adding new coal capacity may not be the most cost-effective solution to help provide export capacity that is available whenever required. **The high start-up and shut-down cost and slow ramp rate of coal plants are not aligned with the real system needs for bundling with large amounts of solar and wind to export 'firm' volumes to other provinces. The focus should be to incentivise investment in a portfolio of highly flexible capacity and solutions, including battery energy storage, pumped hydro storage, open cycle gas units, concentrated solar plants and demand response solutions, in both sending and receiving provinces.**
- Even if coal capacity is required as a long-term backup capacity to cater to scenarios where there is a prolonged low renewable generation, **the focus should be on investigating how to use the existing coal fleet to enable them to perform such backup roles**.

For the new clean energy base and new UHV line plans, the build-up of physical generation and transmission projects should be carefully coordinated so that the bottlenecks for any specific segment do not lead to the under-utilisation of all assets. As most of the clean power will be for exports, coordination with the importing provinces on long-term system planning and short-term operational details is necessary. **For long-term system planning, Inner Mongolia needs to engage with importing provinces to ensure that they reflect the planned power**

imports in their system planning. This can prevent the importing provinces from planning to over-build their expensive local power fleets, such as local new coal capacity. Furthermore, when planning new large-scale clean energy bases, **the long-term strategic value of using green power to produce green fuels should also be considered.**

To better facilitate the export of clean power from large-scale clean energy bases to load centres, inter-provincial power flow and trading should be further enhanced.

- **Allow direct, multi-year green Power Purchase Agreements (PPAs) between renewable energy (RE) developers in the large-scale clean energy bases in Inner Mongolia and the large end-users in the receiving provinces.** The formal signing of such direct bilateral contracts can be organised regularly, similar to the annual bilateral contracts in the West Inner Mongolia (Mengxi) market. The direct multi-year green PPAs can: (1) increase the bankability of the large-scale clean energy bases; (2) help to reduce price volatilities for both the RE developers and large end-users; and (3) help the RE developers to fully realise all the value streams of the large-scale clean energy bases, such as the green attributes for new projects.
- **Organise regular short-term and spot trading to fully utilise available transmission capacity.** The legacy contractual arrangement for physical power flow between dedicated generation projects and receiving provinces can be converted to contract-for-difference (CfD) financial contracts. Regular annual, monthly and multi-day trading for inter-provincial power flows can be provided in the Beijing and Guangzhou power exchanges, similar to the situation with local trading within their respective provinces in China. This can increase contractual flexibility and allow economic power flow when short-term market conditions change. Furthermore, one can consider shifting the per kWh inter-provincial transmission tariff to two-part pricing with a capacity charge set up for the recovery of capital expenditure (CAPEX) of transmission assets. This can incentivise economic power flow and help to provide overall system cost savings. Lastly, studies can be done to see how best to link the spot wholesale electricity markets in Mengxi and Shandong to facilitate the economic day-ahead unit commitment and real-time power flow across the two markets. Experience and lessons learned can then be applied to link Inner Mongolia to the other receiving provinces through day-ahead and spot electricity market trading in the future.

1 Introduction

In June 2023, the Centre for Research on Energy and Clean Air (CREA) and WaterRock Energy Economics published a study, *Resolving near-term power shortages in China from an economic perspective*[1] (hereafter referred to as the *2023 power shortages report*). Its quantitative analytical results show that accelerating capacity expansion of solar, wind and energy storage solutions will be more cost effective than building new coal-power plants to meet the country's growing electricity demands.

In 2024, the central Chinese government released several high-level policies and implementation guidelines to decarbonise the Chinese economy, such as *Opinions on Accelerating the Comprehensive Green Transformation of Economic and Social Development*[2], *Improving Renewable Consumption and Ensuring High Quality Development of Renewables*[3], and *Action Plan for Accelerating the Construction of a New Power System in 2024-2027*[4]. Some of the specific guidelines are consistent with our policy recommendations in the *2023 power shortages report*, such as increasing grid flexibility and improving the price mechanisms and market signals to facilitate investment and consumption of renewables and flexible capacity.

In China, there is a substantial and inherent mismatch between huge resource endowments in western inland provinces and economic activities in coastal and central regions. Building large-scale clean energy bases in the inland provinces and exporting to load centres in coastal and central China is essential to decarbonise the Chinese power sector. In this follow-up report, we use Inner Mongolia as a case study to help understand how large-scale clean energy bases in China can assist both the inland and coastal provinces (for imports) to decarbonise their energy systems.

Currently, Inner Mongolia is China's biggest coal power generator, renewables producer, and

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[1] Zhang L., and Zhang, X. (2023) Resolving near-term power shortages in China from an economic perspective. CREA, https://energyandcleanair.org/wp/wp-content/uploads/2023/06/CREA_WaterRock-Energy-Economics_Resolving-near-term-power-shortages-in-China-from-an-economic-perspective_06.2023.pdf.

[2] China State Council (2024) 关于加快经济社会发展全面绿色转型的意见, https://www.gov.cn/zhengce/202408/content_6967663.htm.

[3] NEA (2024) 做好新能源消纳工作保障新能源高质量发展, https://zfxxgk.nea.gov.cn/2024-05/28/c_1310777105.htm.

[4] NDRC (2024) 加快构建新型电力系统工作方案 (2024—2027年), https://www.ndrc.gov.cn/xxgk/zcfb/tz/202408/t20240806_1392258.html.

power exporter. As of 2022, it had more than 6 terawatts (TW) of exploitable wind and solar power generation capacity[5] in its large land areas and is relatively close to load centres in northern, central and eastern China. By the end of June 2024, Inner Mongolia had 24 gigawatts (GW) of installed solar power and 64 GW of installed wind capacity, with 65 GW of solar[6] and 105 GW of wind[7] in the pipeline. In the medium and long term, it will be one of the main sources of green power for the large consumers in the load centres, supported by its under construction and planned large-scale clean energy bases and export infrastructures to send power to those areas. Since 2022, four 'Sha-Ge-Huang' large-scale clean energy bases have been approved in the northern part of Kubuqi, the southern part of Kubuqi, Ulanbuhe and Tengger[8]. Each clean energy base will have 12 GW of wind and solar, with 4 GW of coal-fired power as support. Four ultra-high voltage (UHV) transmission lines, from west Inner Mongolia (or 'Mengxi') to Jingjinji, Kubuqi to Shanghai, Ulanbuhe to JingJinJiLu, and Tengger to Jiangxi, are being planned to export the clean energy generated from these bases.

Inner Mongolia has strong support from the central government to develop large-scale clean energy bases for exports. In October 2023, the State Council approved a guideline to boost the high-quality development of North China's Inner Mongolia Autonomous Region, invigorating Chinese modernisation[9]. In March 2024, the National Energy Administration (NEA) issued the *Guiding Opinions on Energy Work in 2024*[10], in which one of the recommendations is to strengthen the main grid interconnection between East Mongolia (or 'Mengdong') and Northeast China and promote the extension and strengthening of the North China UHV alternating current (AC) grid to Mengxi. The support from the State Council and NEA will enhance Inner Mongolia as a key national energy supplier and strategic resource base.

In this report, Chapter 2 provides an overview of the Inner Mongolia power sector, followed by

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[5] Energy Bureau of Inner Mongolia Autonomous Region (2022) 内蒙古自治区'十四五'电力发展规划. https://www.cspplaza.com/uploads/files/20220330/1648607366323644.pdf.

[6] Global Energy Monitor (2024) Global Solar Power Tracker, https://globalenergymonitor.org/projects/global-solar-power-tracker/.

[7] Global Energy Monitor (2024) Global Wind Power Tracker. https://globalenergymonitor.org/projects/global-wind-power-tracker/.

[8] Inner Mongolia Daily (2023) 内蒙古稳步推进"沙戈荒"大型风电光伏基地项目建设. https://www.gov.cn/lianbo/difang/202311/content_6917072.htm.

[9] China State Council (2023) 国务院关于推动内蒙古高质量发展奋力书写中国式现代化新篇章的意见, 国发〔2023〕16号. https://www.gov.cn/zhengce/content/202310/content_6909411.htm.

[10] China NEA (2024) 国家能源局关于印发《2024年能源工作指导意见》的通知, 国能发规划〔2024〕22号. https://zfxxgk.nea.gov.cn/2024-03/18/c_1310768578.htm.

reviews of typical practices of existing large-scale clean energy bases and a discussion of key areas for improvement in Chapter 3. Chapter 4 discusses the development of new large-scale clean energy bases and how best to develop those projects to help decarbonise Inner Mongolia and other provinces. Policy-related insights and concluding remarks are developed in Chapters 5 and 6.

2 The historical background of Inner Mongolia's power sector

2.1 Current status

2.1.1 Supply and demand balance

Inner Mongolia has abundant energy resources, and the local government has been keen to leverage this comparative advantage to help develop its local economy. It has been the largest coal producer in China since 2016 and surpassed Shandong to have the highest installed coal-fired power capacity in 2023. Since 2021, Inner Mongolia has led China's wind installed capacity and has been rapidly expanding its solar capacity.

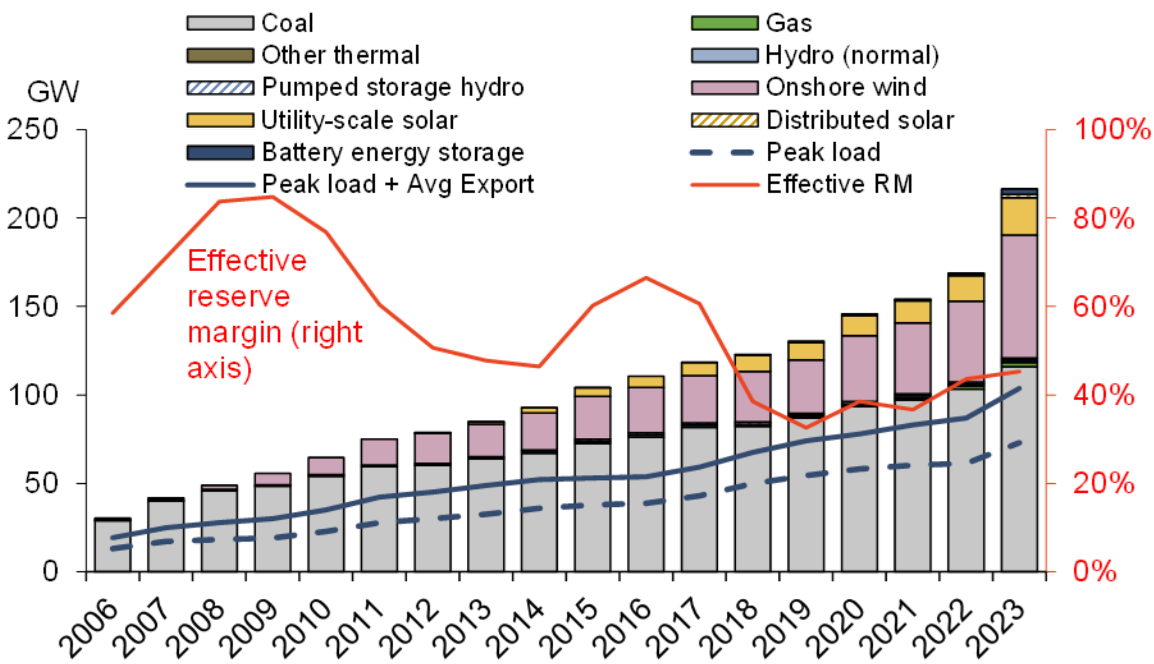


Figure 1 | Installed capacity and peak load in Inner Mongolia

Note: Effective reserve margin = available supply less peak load less average export /peak load. Available factor assumptions: thermal – 90%, hydro (normal) – 25%, pumped storage hydro – 89%, onshore wind – 28%, solar – 18%.

Source: WaterRock Energy created a model based on data published by China Statistical Bureau and China Electric Council (CEC).

Inner Mongolia has been continuously expanding its coal-fired, wind and solar capacity. From 2015 to 2023, installed capacity increased from 73 GW to 116 GW for coal-fired power, 24 GW to 69 GW for wind and 5 GW to 23 GW for solar(see Figure 1). The share of wind and solar in Inner

Mongolia's installed power generation capacity mix increased from 28% in 2015 to 38% in 2023. Thus, by 2023, the wind and solar penetration was relatively high. Flexible capacities, such as battery energy storage and pumped hydro storage, need to be built to integrate intermittent wind and solar electricity resources into the grid.

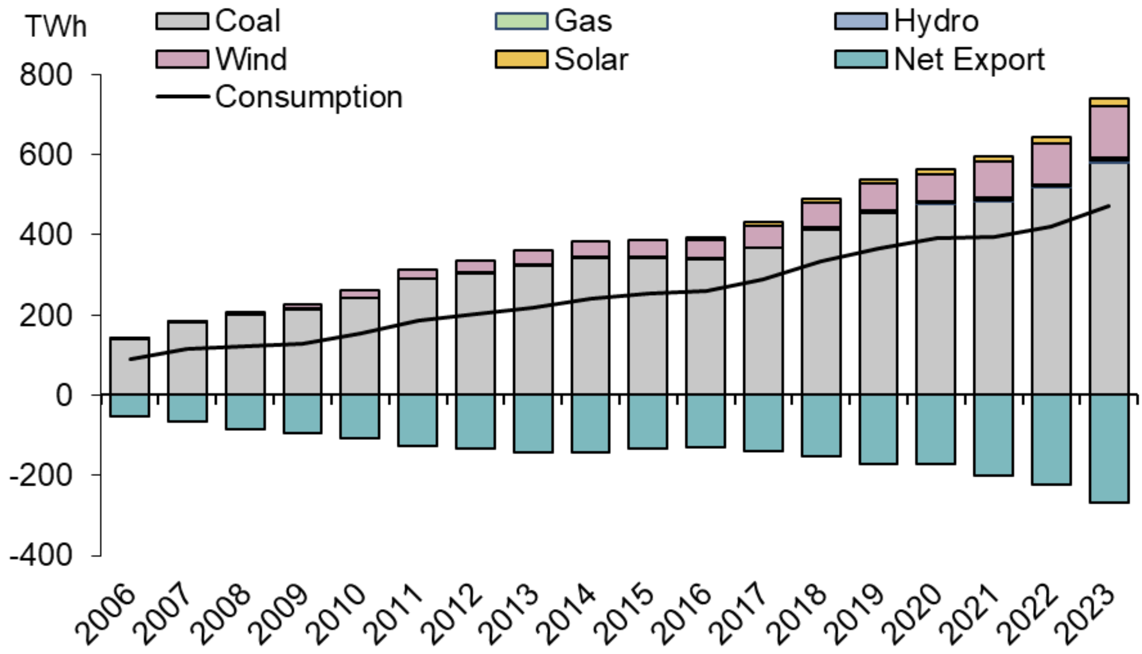


Figure 2 | Local power generation and net electricity exports in Inner Mongolia

Note: Generation data only includes capacity equal to or more than 6 MW.

Source: WaterRock Energy created based on data published by China Statistical Bureau and China Electric Council (CEC).

The share of wind and solar power generation increased from 11% in 2015 to 20% in 2023. 31% of the increase in power supply was from an increase in wind and solar generation, 67% from coal and 2% from gas (see Figure 2). Hence, despite expanding rapidly, wind and solar have only contributed to about one-third of incremental generation in Inner Mongolia in recent years.

Inner Mongolia has the highest power consumption of all the inland provinces in China. In 2023, its electricity consumption was about 472 TWh— 1.5 times the size of the UK's power market. The electricity consumption grew faster than the national average, at a 13% compounded average growth rate (CAGR) in 2006-2017 and 7.1% in 2018-2023. This rapid growth is partly driven by the local government's effort to attract energy-intensive manufacturing industries to the province. Inner Mongolia's peak load was estimated to be about 72GW in 2023[11].

In recent years, Inner Mongolia exported 30-35% of its total power supply (see Figure 2). As discussed in Chapter 3, Inner Mongolia has several UHV transmission lines to export power from the existing large energy bases to load centres in North and East China. If done correctly, the expansion of large-scale clean energy bases in Inner Mongolia can increase wind and solar generation to meet local power consumption growth and increase the share of renewable exports – this will be discussed in detail in Chapter 4.

Inner Mongolia is considered to have a good power supply from a combination of renewables and fossil fuels, with power capacity at an effective reserve margin of more than 40%. However, due to the lack of flexible capacity, it occasionally experiences power shortages during days with unexpectedly high loads.

2.1.2 Regional differences and grid infrastructure

Inner Mongolia has two grid operators (see Figure 3):

- **West Inner Mongolia (Mengxi)** is part of the West Inner Mongolia grid, operated by the Inner Mongolia Power Group (IMPG).
- **East Inner Mongolia (Mengdong)** is part of the Northeast China grid, operated by the State Grid. It accounts for about 20% of Inner Mongolia's consumption and 30% of its generation.

[11] In 2023, total power consumption was 472 TWh in Inner Mongolia. We assume that the average load factor was about 75%; the peak load is estimated to be 72 GW.

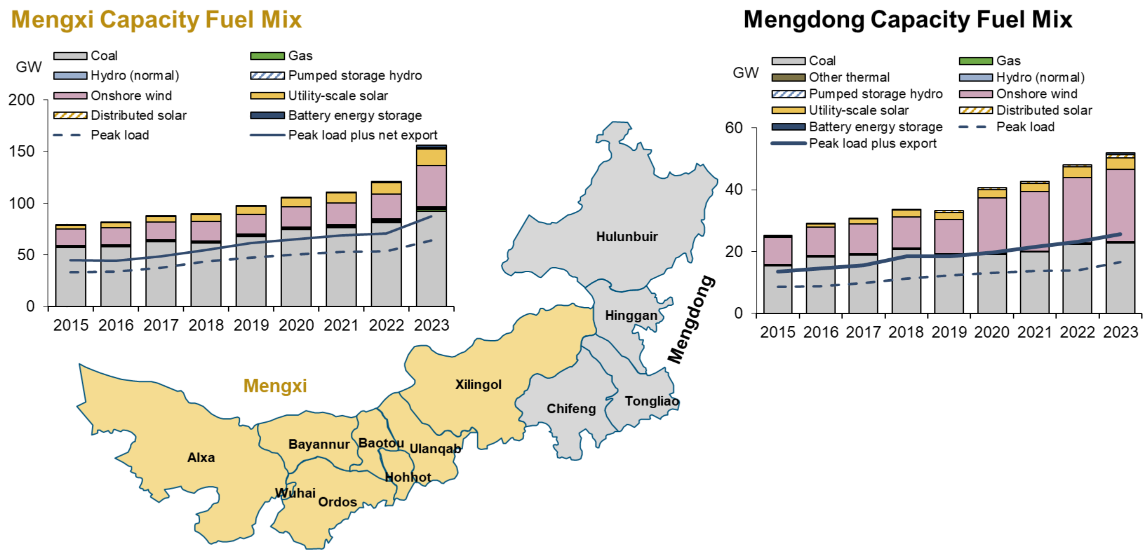


Figure 3 | Mengxi and Mengdong capacity mix

Source: WaterRock Energy estimates based on data from NEA, State Grid and public news.

Inner Mongolia has transmission bottlenecks for power flows across different regions

In Mengxi, the power generation in the western regions, Alxa, Wuhai, Bayannur and Baotou, is primarily consumed locally due to transmission constraints from West to East. The risks of wind power curtailment in these regions are the highest in the Mengxi grid. Ordos and Xilingol have direct export transmission infrastructures with ultra-high voltage, high-voltage direct current (HVDC) and alternating current (AC) lines, so they export relatively large amounts of power from Mengxi. Hohhot exported about 50% of its electricity generation in the past, mainly to the North grid along the dedicated HVDC lines and to neighbouring cities such as Ulanqab (see Figure 4).

In the Mengdong grid, Chifeng, Tongliao, Hinggan, and Hulunbuir are geographically large and have weak transmission interconnection. Mengdong is connected to Heilongjiang, Jilin, and Liaoning provinces in the Northeast of China to form the Northeast grid. The coal-power tariffs in these three northeast provinces are relatively high, at more than Chinese Yuan (CNY) 0.37/kWh. Thus, the cost competitiveness of exporting coal-based power from the Northeast grid is relatively weak.

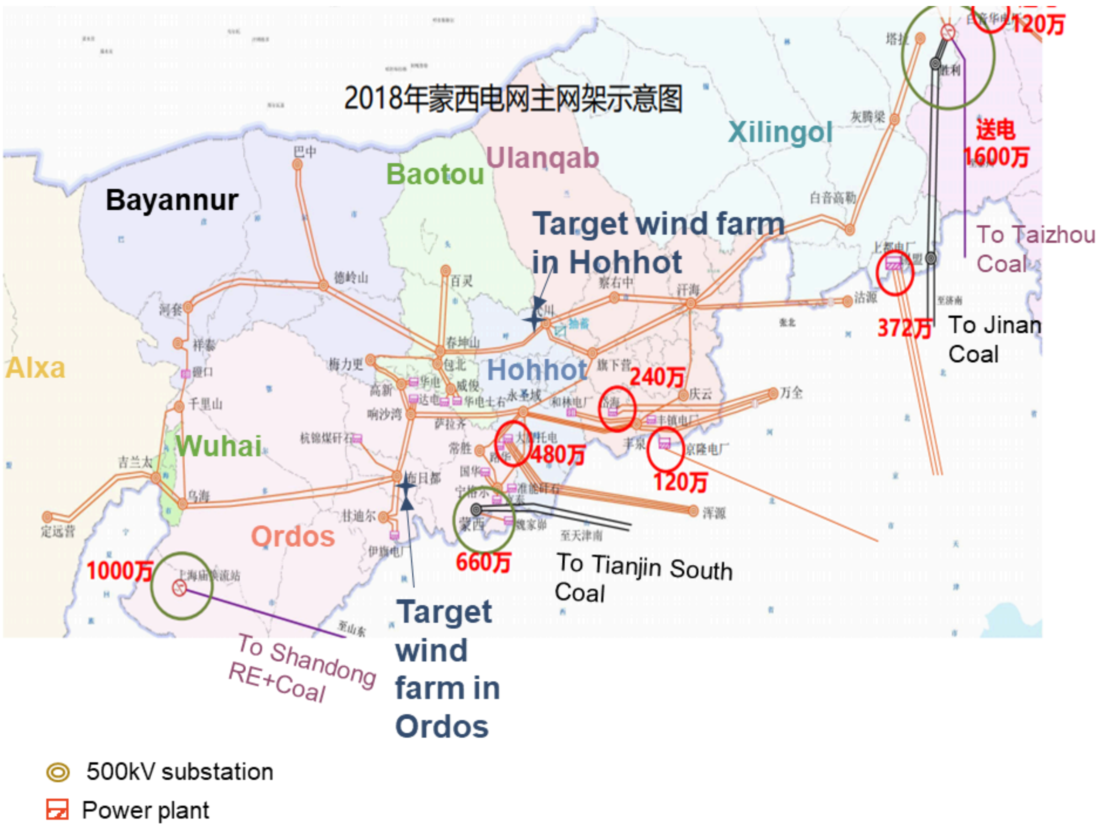


Figure 4 | 500 kV Mengxi grid infrastructure

Source: 蒙西电网主网架发展思路及重大问题研究, WaterRock Energy Research and Analysis.

2.1.3 Renewable curtailment

Inner Mongolia has wind and solar curtailment issues, which is a similar situation in other inland provinces. In 2016, the wind curtailment rate was 21%, and solar was 11%. Curtailment rates dropped continuously from 2016 to 2019 and have remained at less than 10% since 2019 (see Figure 5).

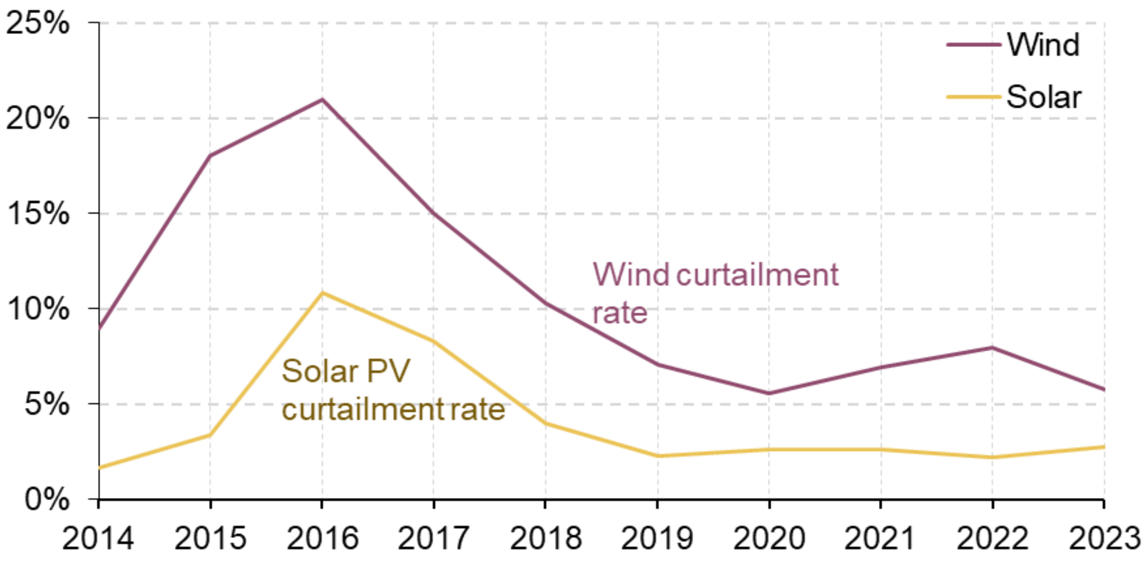


Figure 5 | Wind and solar curtailment rates in Inner Mongolia

Note: Solar and wind curtailment rates are estimated based on curtailment rates of Mengxi and Mengdong released by NEA and New Energy Consumption Monitoring and Warning Centre. 2014-2018 solar curtailment rates are estimated based on various publicly available news

Source: WaterRock Energy analysis based on data from NEA, New Energy Consumption Monitoring and Warning Centre and public news.

The drop in the rate of curtailment in 2016-2019 is mainly driven by the following factors:

- **Re-balancing supply and demand.** There was strong local power demand growth of 12% CAGR in 2016-2019, with an average annual increase in consumption of 4.0 GW. Meanwhile, there was a slowdown in wind capacity expansion in 2016-2019, with an average annual increment of 1.4 GW, down from the 3.0 GW average annual increment in 2009-2015[12]. The slow-down in new wind expansion is partly due to the drop in new approvals of wind projects from the local government to help reduce curtailment[13].

[12] The demand growth and capacity expansion data are based on raw data from China Statistical Bureau and China Electric Council (CEC).

[13] Since 2016, NEA started the National alert system, which categorises curtailment risk into green, orange and red for different provinces. Under the 'red' category, provincial governments need to halt developing and approving new renewable projects; under the 'orange' category, provincial governments need to halt approving new renewable projects. Such practices help to create a negative feedback loop to keep the curtailment rates at a manageable level. Inner Mongolia (Mengxi and Mengdong) was under Red Alert in 2017 and Orange Alert in 2018-2020. Commission of new capacity is mainly from those that were approved in earlier years.

- **Improvement in the grid flexibility** with the commissioning of the 1200 MW Hohhot pumped storage capacity in 2015. The dispatch protocol is gradually shifting from an equal dispatch protocol to economic dispatch[14]. Initiatives are also being pursued to retrofit coal units to run more flexibly.

- **Increase in exports** with the commissioning of new UHV lines. Although the exports are mainly from newly built dedicated mine-mouth coal projects, the wind and solar share in the exports have also been increasing in recent years.

- **Strengthening of local grids**. There was also continued effort to strengthen the provincial grid infrastructure and to help renewable energy (RE) export from low-load regions to high-load regions within Inner Mongolia.

Rapid wind and solar capacity development re-started from 2020 in Inner Mongolia but the curtailment rates have not dropped further and have been kept at 6-8% for wind and about 3% for solar. The average curtailment rate was reported to be 6.4% for wind and 4.7% for solar in the first half of 2024, close to the levels seen in recent years.

2.2 Government plans for renewable energy

The Inner Mongolia government has ambitious plans to expand renewable capacity during the 14th Five-Year Plan (FYP) period to help decarbonise the economy in Inner Mongolia and other provinces (see Table 1).

[14] Under the 'equal' dispatch protocol, the system operator allocates generation quota to different types of generation capacity based on planned utilisation rate consistent with the regulated tariff.

Utilisation hours are adjusted up or down for all technologies based on demand and supply balance. Under economic dispatch protocol, plants are dispatched based on their short-run marginal costs. As solar and wind capacity have almost no short-run marginal cost, they are dispatched before coal and gas capacity under economic dispatch protocol. Adoption of the economic dispatch protocol helps to increase utilisation of wind and solar capacity, especially when the local market is in an over-supplied situation.

Table 1 | Summary of government plans for renewable projects

	Current status	Targets under 14th FYP and long-term plans
General direction	● Inner Mongolia has been expanding all types of power sources in the past decade.	● To rapidly expand wind and solar capacity and build multiple GW renewable bases; ● To become one of the pioneer provinces with renewables as the main energy sources in the local power grid.
Overall renewables targets	● **Capacity:** 2020 – RE* 52 GW, thermal 94 GW; 2023 - RE 98 GW, thermal 118 GW ● **Generation**: 2020 - RE 85 TWh, thermal 478 TWh; 2023 - Renewables 154 TWh, thermal 587 TWh	● To increase renewable capacity to a level higher than the thermal capacity by 2025. ● To increase renewable generation to a level higher than thermal generation by 2030.
Wind and solar targets	● **Wind:** 2020 - 38 GW, of which 32 GW for local consumption and 6 GW for export; 2023 - 70 GW ● **Solar**: 2020 - 12 GW, of which 100% for local consumption; 2023 - 23 GW	● **Wind:** 2025 - 89 GW, *of which 57 GW for local consumption and 32 GW for export* ● **Solar**: 2025 - 45 GW, *of which 38 GW for local consumption and 7 GW for export* ● Rapid expansion of new clean energy bases (details covered in Chapter 4.1).
Flexible capacity	Only one 1.2 GW existing pumped hydro storage capacity in Hohhot.	● To complete the 1.2 GW pumped hydro storage capacity in ChiFeng and start construction of several other pumped hydro storage capacity.[15] ● To increase battery energy storage solution (BESS) to more than 5 GW by end 2025. ● To explore and develop green hydrogen projects. ● To increase the pace in the development of peaking gas capacity and retrofit existing coal capacity to increase its operational flexibility.

[15] There is inherent limitation to develop new pumped hydro storage capacity in Inner Mongolia due to limitation of water resources in the area.

	Current status	Targets under 14th FYP and long-term plans
Grid infrastructures	Several UHV lines but utilisation rates are below 40% (details covered in Chapter 3.1).	• To fasten the pace of construction of associated clean energy bases for the existing UHV lines. • To increase the renewable share of export via the existing UHV lines. • To strengthen transmission connections between Inner Mongolia and North China and between Mengdong and Northeast China; and build new green UHV lines to export green power to North and Central China. The share of renewables in export via new UHV lines has to be more than 50%. • To deploy Voltage sourced converter (VSC) transmission technology to improve grid flexibility.

Note: *Renewables (RE) include solar, wind, hydro and biomass. Source: Inner Mongolia 14th five-year and 2035 long-term development plan[16], Inner Mongolia 14th renewable energy plan[17], Inner Mongolia 14th energy plan2, and WaterRock Energy estimates and analysis.

2.3 Challenges for decarbonisation

Inner Mongolia has ambitious plans to expand renewable capacity, but it must overcome several challenges to the energy transition.

- **Lack of flexible capacity**. Inner Mongolia has more than sufficient physical generation capacity to meet its energy demand and export needs. However, almost all dispatchable capacity comes from coal-fired power. Furthermore, some coal-fired power plants supply both power and heat to end-users, and the heating requirement can determine their operation. For example, heating requirements are high in winter, so those coal-fired power plants have to be run at high utilisation rates. Such operation modes reduce the system flexibility. Thus, the system is fundamentally short of flexible peaking capacity, making it incapable of responding quickly to sudden fluctuations in load and generation sources. To decarbonise the grid, Inner Mongolia will need to build much more flexible capacity, including battery energy storage, pumped hydro storage, open cycle gas units, and concentrated solar plants, and deploy demand response solutions. Expanding coal

[16] Inner Mongolia Autonomous Region People's Government (2021) 内蒙古自治区国民经济和社会发展第十四个五年规划和2035年远景目标纲要. https://www.ndrc.gov.cn/fggz/fzzlgh/dffzgh/202106/t20210628_1284322.html.

[17] Energy Bureau of Inner Mongolia Autonomous Region (内蒙古自治区能源局) (2022) 内蒙古自治区"十四五"可再生能源发展规划. http://nyj.nmg.gov.cn/openApi/downloadPdf?docid=2012218.

capacity will not address the lack of flexibility nor meet the operational needs of the evolving system. The new power system needs resources capable of frequent cycling, fast ramping and meeting higher reserve and frequency regulation requirements. Coal-fired power plants have slow ramp rates and long start-up times, and their start-up and shut-down costs are high. Thus, they are not technically suitable for providing these operational characteristics.

- **Grid enhancement**. The current grid in Inner Mongolia was primarily designed assuming large coal-fired power plants would be the dominant electricity source. Because of its large geographical size, Inner Mongolia has internal transmission constraints. To shift the power sector to be primarily renewable-based from 2030 onwards, a substantial amount of grid investment and new grid technologies will need to be deployed.

- **Just energy transition**. Local economies and jobs in cities such as Wuhai and Erdos have heavily depended on coal mining and coal-based industries. Shifting economies away from coal and retraining the workforce for the 'new' green economy[18] is a challenging task for both central and local governments. To support the transition, Inner Mongolia has been promoting the investment of manufacturing bases and operation and maintenance (O&M) bases for an integrated supply chain of wind, solar, battery energy storage and green hydrogen. It will be a long process requiring massive effort from the governments, enterprises, and the local population.

- **Coordination with other provinces**. Inner Mongolia plans to export a large amount of its incremental wind and solar generation to other provinces. This will require new export infrastructures and coordination with receiving provinces. For example, according to its 14th five-year energy plan, of the additional 55 GW wind and 33 GW solar capacity expected in 2021-2025, more than 50% of the wind capacity and 20% of the solar capacity are to be exported to other provinces. Increasing the utilisation rates and share of renewable exports through the existing UHV lines and building new ones require close coordination with the importing provinces, especially to prevent over-building expensive local fleets, such as new coal capacity. It remains to be seen whether such an export plan can be met.

[18] Yang, Y., Dong W., and Hui J. (2024) A Just Transition for Coal Regions: Learning from Two Coal Cities in Western China. https://www.belfercenter.org/research-analysis/just-transition-coal-regions-learning-two-coal-cities-western-china.

3 Existing clean energy bases in Inner Mongolia

3.1 Overview of existing large-scale clean energy bases in Inner Mongolia

The idea of developing large-scale clean energy bases was first introduced in the 2007 China NEA's *Renewable Energy Mid- to Long-term Development Plan*[19]. The NEA aimed to build three GW-sized wind farms in Jiangsu, Hebei and Inner Mongolia by 2010, as well as six GW-sized inland wind farms across China, including one in Inner Mongolia Huitengxile, by 2020. The plan also initiated the construction of large solar energy bases in the Gobi deserts and barren land in Inner Mongolia, Gansu and Xinjiang. However, in the 2010s, investment in these large-scale clean energy bases slowed down, partly due to the high renewable energy curtailment rates in Northwest China and Inner Mongolia during 2010-2015.

The rapid growth in local energy demand, the slowdown in local capacity expansion, and the expansion of UHV lines to export power from large-scale clean energy bases have helped to quickly reduce renewable curtailment rates. Since 2021, China has reembarked on the expansion of clean energy bases with the announcement of multiple large-scale clean energy bases (see Figure 6).

[19] NEA (2007) Renewable Energy Long-term Development Plan (可再生能源中长期发展规划). https://www.ndrc.gov.cn/xxgk/zcfb/tz/200709/t20070904_965446.html.

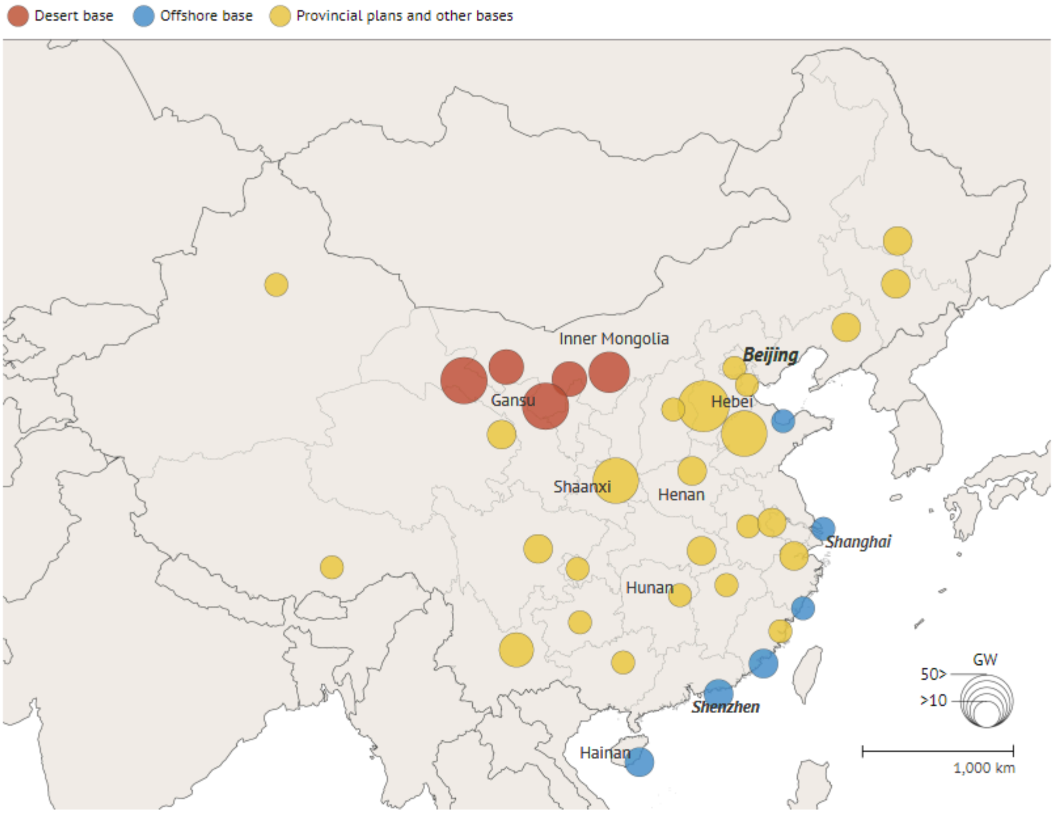


Figure 6 | China's announced clean energy bases in the 14th FYP[20]

Note: Clean energy bases and provincial clean energy installation plans with targeted installed wind and solar capacity by 2025 indicated by the size of the circles. The desert bases (red circles) in western Inner Mongolia and Gansu, offshore wind bases across the coast (blue) and provinces' own clean energy expansion (yellow) will all provide electricity to the demand centres in the east.

One key lesson from the first round of clean energy base investment in 2007-2015 is that investment in large-scale clean energy projects in inland provinces needs to be linked with the development of export transmission infrastructures to export to load centres. Due to the need for long-distance transmission, UHV direct current (DC) and alternating current (AC) lines are typically used in China.

Approval for UHV lines comes from central government bodies, including the National Energy Administration (NEA) and the National Development and Reform Commission (NDRC), a process that can be lengthy. The first UHV line, the 1000 kV JiDongNan-NanYang-Jingmen UHV

[20] Myllyvirta, L. and Zhang, X. (2022) Analysis: What do China's gigantic wind and solar bases mean for its climate goals? https://www.carbonbrief.org/analysis-what-do-chinas-gigantic-wind-and-solar-bases-mean-for-its-climate-goals/.

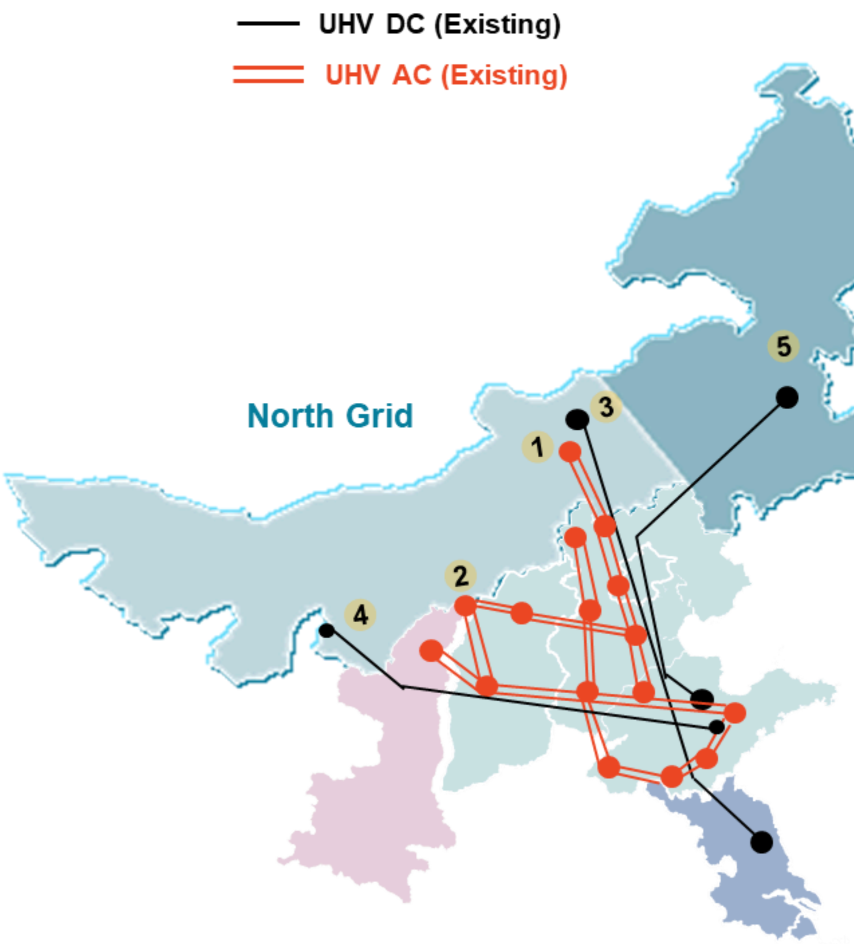
AC line, was approved in August 2006 and commissioned in January 2009[21]. The State Grid's original UHV plans reflected a strategy of interconnecting the three largest regional grids of North China, East China and Central China. In 2006-2013, the approval progress and development of the UHV transmission plans were slow and multiple UHV lines were on hold due to concerns about potential cascading power failures across the country if those inter-regional UHV AC lines were constructed.

Between 2010 and 2015, high renewable curtailment rates in the inland provinces became a growing concern, while heavy smog and worsening air quality plagued Beijing and many other Chinese cities. The driving reason of China's UHV system infrastructure development shifted from broad strategic considerations of optimal grid structure to the practical needs of ensuring supply adequacy and promoting cleaner air in load centres. The NEA accelerated approvals, greenlighting nine UHV projects in 2014 and additional ones in the following years. All five existing UHV lines out of Inner Mongolia were approved in 2014-2016 (see Figure 7).

- Xilingol-Jinan UHV AC, Mengxi-Tianjin UHV AC, and Ximeng-Taizhou UHV DC were approved in 2014 and commissioned in 2016. The associated large energy bases are dedicated coal power projects using brown coal in Xilinhaote[22].
- Zhalute-Shandong and Shanghaimiao-Shandong UHV DC lines were approved in 2015-2016 and commissioned in 2018. The associated energy projects include wind and solar projects, but their share has been low, accounting for less than one-third of total export volumes in 2019-2023.

[21] People's Daily (2009) 首个特高压输电工程建设纪实：在创新中破冰起航. https://www.gov.cn/ztzl/2009-01/23/content_1213288.htm.

[22] The power projects include 4x600 MW and 2x660 MW Shangdu coal-fired power units (上都发电厂). Those projects use lignite in the Weijiamao coal mine.



UHV/HV Lines and Export Capacity	Dedicated Generation Sources and Capacity
1. 1000 kV UHV Xilingol-Jinan AC, 9.0 GW, Jul 2016	Dedicated coal ((7 new coal plants, totaled 8.62 GW); Possibly with RE in the future
2. 1000 kV Mengxi – Tianjin South UHV AC, 6 GW, Nov 2016	Dedicated coal; likely with wind/solar in the future
3. ±800 kV Ximeng-Taizhou UHV DC line, 10 GW, Sep 2017	Dedicated Coal; likely with wind/solar in the future
4. ±800 kV Shanghaimiao – Shandong, 10 GW), H2 2018].	Dedicated Coal + wind + solar **(15-50% wind + solar)**
5. ±800 kV DC Zhalute – Shandong, 10 GW [commissioned in end 2017].	Dedicated Coal + wind + solar **(30-40% wind and solar)**

Figure 7 | UHV DC and AC grid connectivity of Inner Mongolia

Source: WaterRock Energy analysis based on data from NEA and public news.

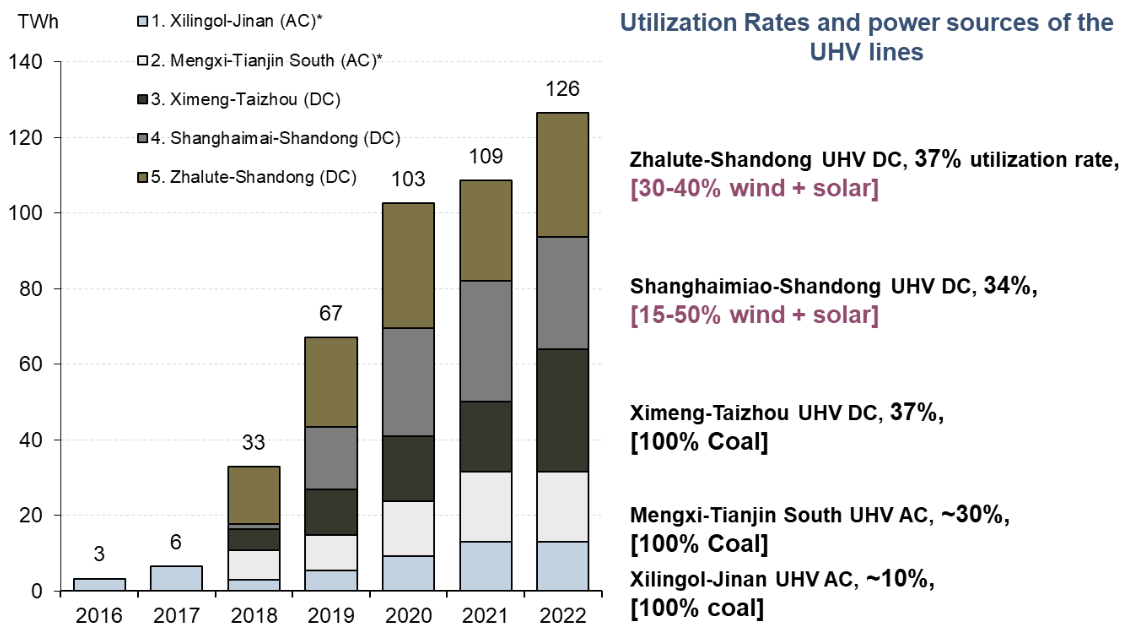


Figure 8 | Utilisation rates of the UHV DC and AC Line of Inner Mongolia

Note: The transfer volumes of the two UHV AC lines are estimated for 2021 and 2022.

Source: WaterRock Energy analysis based on data from NEA and public news

Even though the UHV lines have been running for more than eight years, the utilisation rate has been relatively low, at less than 40%, and the share of renewable energy in exports has also been low[23] (see Figure 8). The low utilisation rate is partly because the construction of the UHV lines, associated power projects, local grid enhancement projects and potential demand from importing provinces are not optimally coordinated.

3.1.1 Case study of Zhalute-Shandong UHV line

The Zhalute-Shandong UHV project is used to illustrate project planning, approval and operation. The plan to build a UHV line exporting power out of the Northeast grid was initiated in the early 2010s, and the local government started the feasibility study for the Zhalute-Shandong ±800 kV UHV DC line in 2015. The project was officially approved by the NEA and the NDRC in August 2016. Construction started immediately and the line was commissioned in December 2017. It originates in Zhalute Banner of Tongliao City in Inner Mongolia, and ends in Qingzhou City of Shandong Province. The total length of the line is 1,234

[23] Calculated based on 2021 and 2022 NEA reports (2021年度全国可再生能源电力发展监测评价报告 http://www.gov.cn/zhengce/zhengceku/2022-09/23/content_5711253.htm and 2022年度全国可再生能源电力发展监测评价报告 http://zfxxgk.nea.gov.cn/2023-09/07/c_1310741874.htm).

kilometres with a transmission capacity of 10 GW.

The primary aim of this project is to address the high wind curtailment issue in East Inner Mongolia and Jilin province. The utilisation rate of the Zhalute-Shandong line was less than 40% in 2018-2022, with only 30-40% of the export volume coming from renewable sources (see Figure 9).

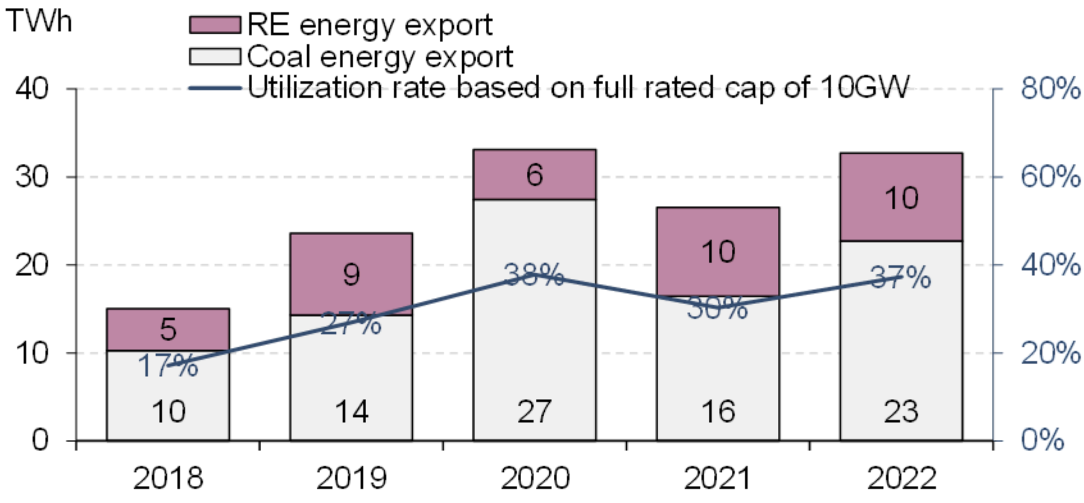


Figure 9 | RE and coal energy export from Zhalute-Shandong UHV line

Source: WaterRock Energy analysis based on data from NEA and public news.

The relatively low utilisation rates are mainly because of slow progress on the associated dedicated power generation projects and the downstream grid enhancement projects. After the Zhalute-Shandong ±800 kV UHV DC line was approved and then built, it took a long time to plan associated dedicated power projects. As of September 2024, associated large-scale clean energy projects through the Zhalute-Shandong UHV DC line are still under construction, including:

- Jingneng International's Tongliao 2.38 GW wind power project in Tongliao prefecture, including the 1.38 GW wind power base project in Keerqin District, Tongliao City, and the 1 GW wind power base project in Keerqin Zuoqi, Tongliao;
- 3 GW dedicated new wind project in Jilin West under the framework agreement between the Jilin and Shandong governments, which is to be built in the 14th FYP period; and
- Multiple associated 500 kV transmission related projects.

In east Inner Mongolia, the downstream 500 kV and 220 kV lines are also weak, and the expansion of the 500 kV transmission lines has been progressing slowly.

3.2 Commercial and policy framework for large-scale clean energy projects

As discussed in session 2.2.2 of the *2023 power shortage report*, current inter-provincial trading is primarily based on rolling annual contracts between the provincial governments (地方政府间框架协议) or mandated by the central government (国家指令性计划). The power scheduling mainly follows annual and monthly contractual quantities. The power exports from Inner Mongolia to different provinces using the existing UHV lines follow this practice. Although such an arrangement can broadly address the spatial disparities between energy resources and load centres, it is too rigid to address the mismatches in supply and demand on shorter timescales (weekly, daily and hourly) or to respond to unexpected changes in the supply and demand balance.

The net-back pricing principle is adopted for renewable power exports. Under this model, the tariff in the export province is determined based on the average tariff in the import province, minus the relevant transmission cost and loss. Depending on the supply and demand dynamics, discounts may be offered by the export province to incentivise the uptake of power in the import provinces. For example, power export from the Northeast grid to Shandong via the Zhalute-Shandong UHV DC line is CNY 0.30-0.33/kWh.

- In the import province, Shandong, the renewable tariff is about CNY 0.40/kWh;
- Set by NEA, the UHV transmission charge is all energy-based and at CNY 0.0412/kWh, and transmission loss is 2.69%[24];
- The local transmission tariff for export is about CNY 0.03/kWh;
- Thus, the net-back pricing without any discount is estimated to be about CNY 0.318/kWh (see Figure 10).

[24] This is based on the 2024 inter-provincial transmission grid tariff table from State Grid (2024年国家电网有限公司跨省跨区交易各环节输电价格-北极星电力新闻网 (bjx.com.cn)).

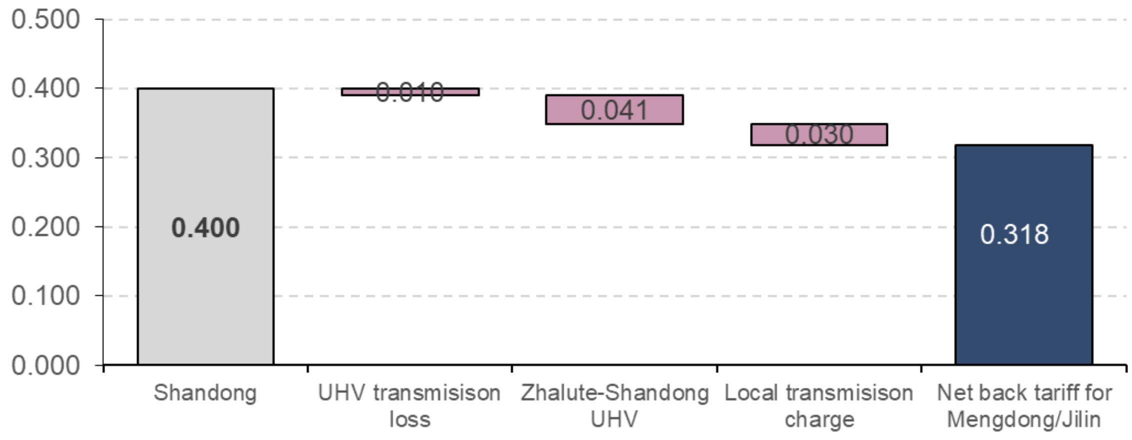


Figure 10 | Net-back tariff of renewable exports for Mengdong or Jilin

Source: WaterRock Energy analysis based on data from NEA, Shandong power exchange and public sources.

In 2019, NEA released a policy to encourage the signing of 20-year long-term power purchase agreements (PPAs) for local consumption and export projects[25]. For export projects, the policy states the following key points:

- Exporting provinces with inter-provincial transmission infrastructures are encouraged to prioritise planning grid-parity wind and solar projects. These projects would be based on the regulated on-grid coal tariff in the receiving provinces, minus transmission tariffs, with a possible slight discount.
- The government departments and provincial grid companies in the receiving provinces are responsible for ensuring the consumption of imported volumes. Under framework agreements between the grid companies of the sending and receiving provinces, the relevant provincial departments and provincial grid companies can sign long-term fixed-price contracts (no less than 20 years).

In the past, multi-year commercial framework agreements with a guiding price for export renewable projects have been used between the local governments of the exporting province and importing province. For example, the 3 GW dedicated new wind base in Jilin West

[25] NDRC and NEA (2019) 关于积极推进风电、光伏发电无补贴平价上网有关工作的通知. https://www.nea.gov.cn/2019-01/10/c_137731320.htm

exporting to Shandong via the Zhalute-Shandong UHV line is under this framework.

3.3 Key areas for improvement

3.3.1 Better coordinating construction of physical infrastructure

The generation and transmission projects need careful coordination to realise their full value. As discussed in Chapter 3.1, the delays in associated generation and local transmission infrastructure have contributed to the low utilisation rates of the UHV lines and possibly also contributed to under-investment and under-utilisation of large-scale clean energy bases in Inner Mongolia.

Furthermore, the existing UHV lines have either no physical grid connection with the local grid[2] or weak connection at best, making it impossible to better utilise existing resources for export. The project should be well planned and implemented, especially for the UHV lines and relevant local 500 kV and 220 kV transmission lines.

More can be done to expand downstream local 500kV and 220kV transmission grid infrastructures to effectively integrate them into the regional grids and tap into existing coal and clean energy bases in Inner Mongolia. Distribution grid infrastructures can also be strengthened. The downstream grid strengthening plans and associated energy bases should prioritise decarbonisation and reliability. Instead of building large new coal projects, a detailed analysis should be carried out to assess how to efficiently build local transmission infrastructure to source power from existing coal fleets (if required) and new clean energy bases. Such an approach could help to reduce the costs and long-term risk of stranded coal assets.

3.3.2 Enhanced trading arrangements

There are at least two enhancements for inter-provincial trading arrangements for large-scale clean energy bases, namely:

- Further enhancing short-term, spot day-ahead and real-time inter-provincial trading; and
- Facilitate signing multi-year long-term green PPAs between RE developers in the sending provinces and large end-users in receiving provinces.

More flexible inter-provincial trading

Inter-provincial trading at short-time intervals and spot day-ahead and real-time should be further facilitated, and China has been making progress on this. Ad-hoc market trading for inter-provincial power flow for annual and monthly trading has been organised in the Beijing Power Exchange for the State Grid network and the Guangzhou Power Exchange for the China Southern Grid network. Some regional grids, like the Northeast grid, have also started to organise inter-provincial spot trading by utilising any unused inter-provincial transmission capacity for power flow.

The current ad-hoc inter-provincial trading arrangements are designed not to influence provincial generator output planning, and the allowed market trading volumes remain low, at 10-15% for inter-provincial power flow[26]. Thus, the year-ahead scheduling based on annual contracts remains essentially unchanged. When situations change within the year, the ability to re-calibrate and re-optimise the scheduling of existing power capacity for power import/export is still limited. Such a rigid arrangement has contributed to the power shortages experienced in some provinces in 2022, as discussed in the *2023 power shortages report*.

Thus, more flexible inter-provincial trading arrangements can be made across China. Detailed recommendations are provided in Chapter 5.2.

Multi-year green PPAs

As the Chinese power sector continues to be reformed with wholesale spot electricity markets being set up in many provinces and a relatively high degree of retail competition, provincial governments and provincial grid companies should increasingly play a facilitating role instead of directly entering into contract negotiation and even becoming the counterparties of framework agreements. In the next few years, multi-year green PPAs between the RE developers in the sending provinces and the large end-users in the load centres should be allowed and encouraged. Multi-year, long-term green PPAs (or long-term corporate PPAs) between the RE developers and end-users can help to increase the bankability of the large-scale clean energy bases, and de-risk potential market price fluctuations for both RE developers and large end-users.

[26] Based on data from China Electricity Council (CEC), in 2023, total inter-provincial power flow was 1159 TWh. Of which, 129 TWh is based on physical market trading. Thus, the share of market trading was about 11% in 2023.

Large end-users, such as international manufacturers or Chinese manufacturers who export to Europe and the US, could be willing to pay higher prices for the green attributes of the new capacity than the existing ones. This is because the green attributes from the newly built solar and wind capacity in the large-scale clean energy bases can meet the 'additionality' criteria under the international standard of clean energy accounting approaches[27]. Allowing direct negotiation and signing multi-year green PPAs between end-users and RE developers could help unleash the potential value stream of new large-scale clean energy bases, which is hard to realise in non-market arrangements, such as under framework agreements between provincial governments.

In the next few years, local governments and the national power exchanges can consider organising the trading and signing of multi-year direct green PPAs for green power imports/exports across different provinces, similar to what has been done for the local annual green PPAs.

[27] Greenhouse Gas Protocol (2023) Greenhouse Gas Protocol Standards Update Process

Detailed Summary of Responses from Scope 2 Guidance Stakeholder Survey. https://ghgprotocol.org/blog/ghg-protocol-releases-summary-scope-2-guidance-survey-feedback.

4 New clean energy bases in Inner Mongolia

4.1 Plan of new clean energy bases in Inner Mongolia

After China pledged to reach 2030 carbon peaking and 2060 carbon neutrality at the 75th United Nations General Assembly in September 2020, the Chinese central government followed up with announcements to build large new wind and solar bases in inland provinces in China. Many planned large renewable bases are located in ‘Sha-Ge-Huang’ areas, which means arid, barren regions like the Gobi desert. They are dubbed the ‘Sha-Ge-Huang’ clean energy bases. In 2021-2025, the Chinese government plans to start constructing 200 GW of wind and solar capacity in the ‘Sha-Ge-Huang’ clean energy bases, of which 70% exported out of the provinces. In 2026-2030, the aggregate planned capacity is 255 GW, of which 65% will be exported out[28]. With such a large amount of capacity addition, the ‘Sha-Ge-Huang’ clean energy bases will be one of the main contributors to new wind and solar capacity addition from the period 2021-2030, and their timely implementation will be important to help reduce carbon emissions in China in the next decade.

4.1.1 New large-scale clean energy bases for existing UHV lines

Under its 14th Five-Year renewable plan, Inner Mongolia plans to build several associated clean energy bases for the existing UHV lines[17] (see Figure 11), including:

- in Xilingol, phase I 7 GW wind base and phase II 4 GW wind base for the 1000 kV UHV Xilingol-Jinan UHV AC line and ±800 kV Ximeng-Taizhou UHV DC line;
- in Erdos, Alxa and Bayannur, phase I 4 GW renewable base (3.8 GW wind plus 0.2 GW solar) and phase II 4 GW solar project for the ±800 kV Shanghaimiao – Shandong UHV DC line;
- in Tongliao and Xing’an, 4 GW associated wind base for the ±800 kV Zhalute – Shandong UHV DC line; and
- 4 GW renewable base (1.2 GW wind plus 2.8 GW solar in the mining areas in Hohhot and Erdos) for the 1000 kV Mengxi – Tianjin South UHV AC line.

[28] NDRC and NEA (2022) 以沙漠、戈壁、荒漠地区为重点的大型风电光伏基地规划布局方案. http://www.spic.com.cn/zhxx/202203/t20220307_318670.html.

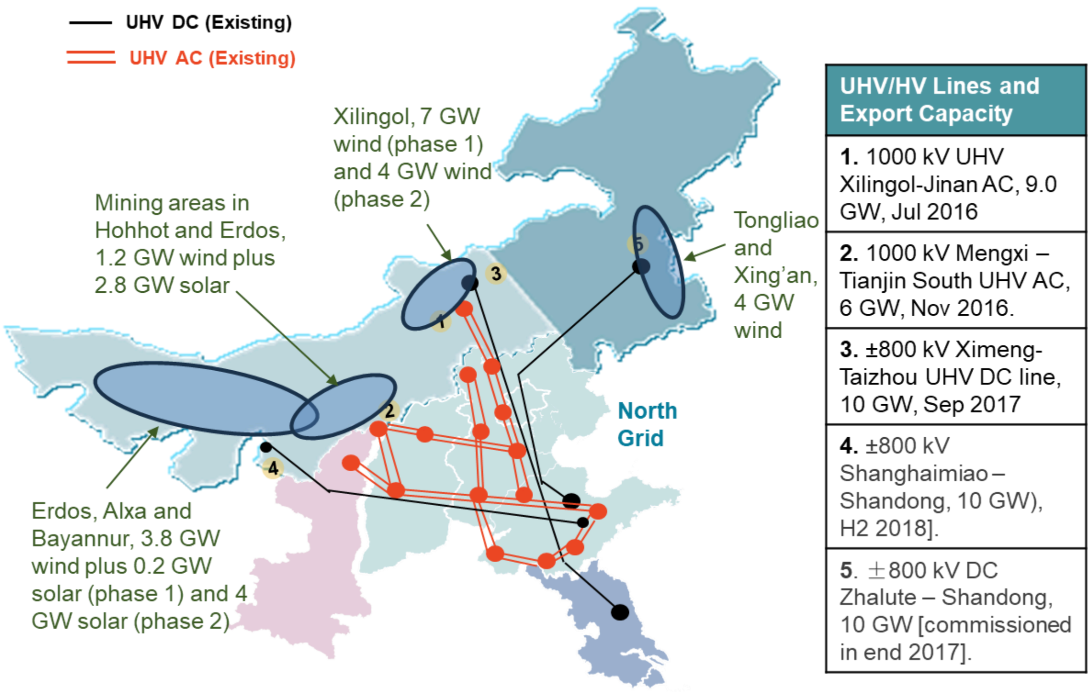


Figure 11 | New clean energy bases for existing UHV lines

Source: WaterRock Energy analysis based on data from NEA and NDRC.

4.1.2 'Sha-Ge-Huang' clean energy bases with new UHV lines

In addition to the new large-scale clean energy bases for existing UHV lines, Inner Mongolia also plans to build new 'Sha-Ge-Huang' clean energy bases (single project starting from 10 GW) with new UHV lines (see Figure 12). Four desert clean energy bases were approved in 2022 to be built in Inner Mongolia. Each base will have 8 GW solar and 4 GW wind, with 4 GW coal-fired power as support and a dedicated UHV line for export[29]. The central government has designated state-owned enterprises to lead the generation capacity and infrastructure development for each of the new desert bases as below:

- The central and northern part of Kubuqi. The lead company is China Three Gorges Corporation. China Three Gorges Corp started to build a 1GW solar project in 2022 and commissioned it in 2023. The electricity generated from these solar projects is currently for local consumption. The associated UHV line runs from western Inner Mongolia to Jingjinji, the ±800kV Mengxi-Jingjinji UHV DC project and is one of the key grid projects that are

[29] Inner Mongolia Daily (2023) 内蒙古稳步推进"沙戈荒"大型风电光伏基地项目建设. https://www.gov.cn/lianbo/difang/202311/content_6917072.htm.

expected to start construction by the end of 2024, according to a document released by the central government in May 2024[30].

- The southern part of Kubuqi. Huaneng Group is leading the project and has started constructing a 1GW solar PV project to kick-start the base[31]. The planned UHV line is from Kubuqi to Shanghai, but it has not yet been approved.

- Ulanbuhe. Inner Mongolia Power Investment Cooperation and Inner Mongolia Energy are leading the project[32] and have also started with a 1GW solar project[33]. The planned UHV line is from Ulanbuhe to JingJinJiLu. A feasibility study has been completed, but as of August 2024, the project had not been officially approved[34].

- Tengger in the western part of Alashan league. Huadian Group, China Resource Power Holdings Company Limited and other central state-owned firms plan to develop the base. The planned dedicated UHV line is from Tengger to Jiangxi. It had completed a feasibility study but as of September 2024 had not been officially approved

Up to mid-2024, the state-owned power companies each built 1 GW of solar PV projects to meet the minimum requirement for leading four large-scale clean energy bases.

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[30] NEA (2024) 国家能源局关于做好新能源消纳工作 保障新能源高质量发展的通知. https://www.gov.cn/zhengce/zhengceku/202406/content_6956401.htm.

[31] China Huaneng (2024)华能库布齐新能源基地：光驭沙海 逐绿前行. https://www.chng.com.cn/detail_mtbd/-/article/SIgvLjX6a9gO/v/1220802.html.

[32] 北极星风力发电网 (2023) 风电3.5GW！总投资771亿的新能源项目正式立项! https://m.bjx.com.cn/mnews/20231010/1336050.shtml.

[33] Feng C. (2023) 国内首批首个千万千瓦级“沙戈荒”基地先导工程一期并网发电. https://www.cpnn.com.cn/news/hy/202312/t20231229_1665101.html.

[34] Cao M. (2024) 特高压“高速路”将内蒙古绿电送四方 加快构建新型电力系统. https://www.escn.com.cn/20240814/322094c439a34e14acac8cb358eb93dc/c.html.

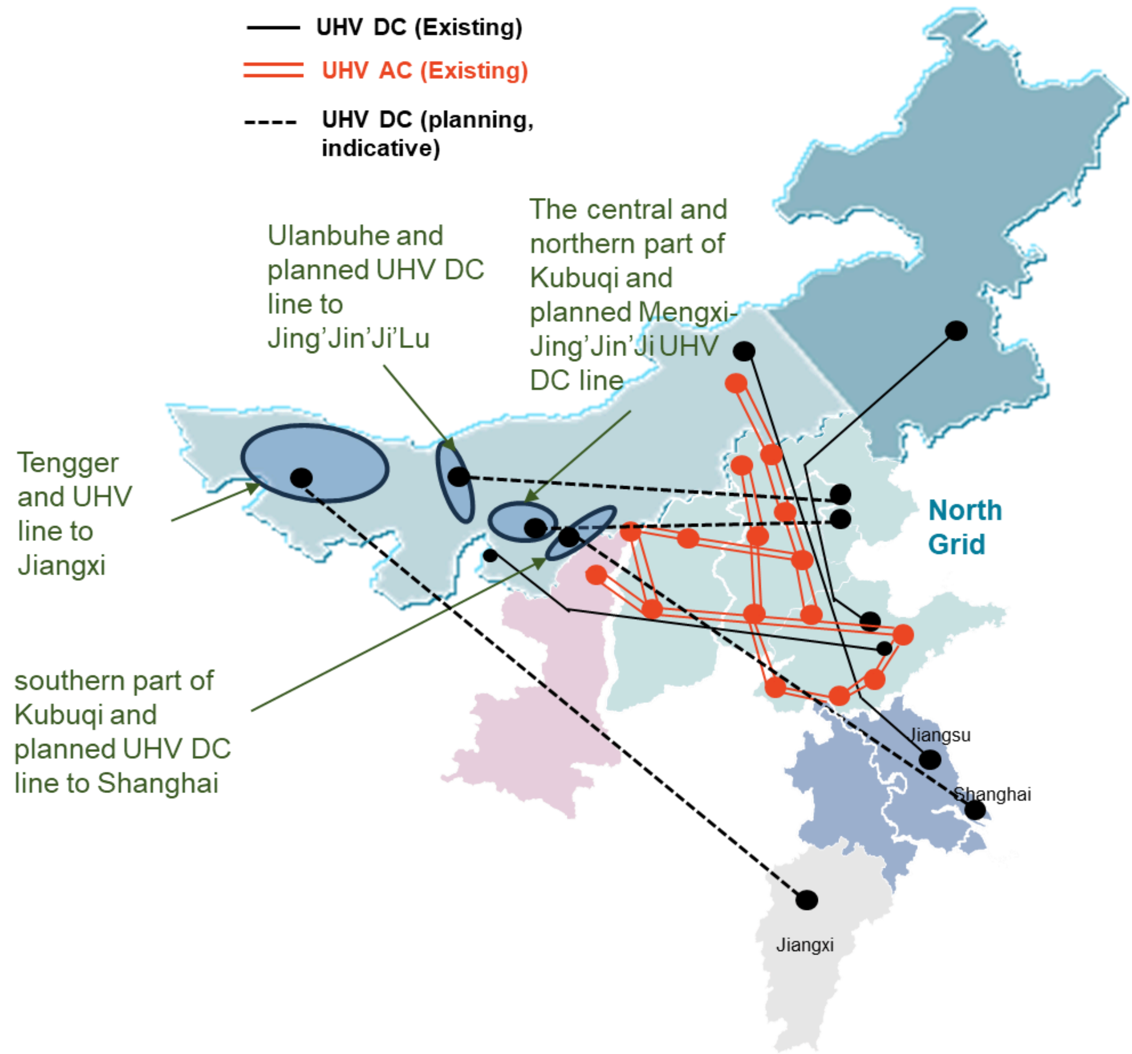

Figure 12 | New clean energy bases for new UHV lines

Source: WaterRock Energy analysis based on data from NEA and NDRC.

4.2 Fundamental changes

Compared to the large-scale clean energy projects planned and built between 2008 and 2020, new clean energy bases feature several key fundamental changes:

- New clean energy projects do not require any subsidies from the central government and are more cost effective than alternative energy supply options.
- The development of voltage-sourced converter (VSC) HVDC technology enables the export of a high share of intermittent renewable capacity to load centres.

- New clean energy projects provide long term strategic value to produce green fuels such as green hydrogen to help decarbonise non-power sectors in China.

4.2.1 Cost effectiveness

As discussed in Chapter 3.3 of the *2023 power shortages report*, the levelized cost of energy (LCOE) for new utility-scale solar and wind projects is more than 10% cheaper than the new coal projects in China in 2022. In the past two years, the project cost of solar and wind projects has fallen more than expected.

- The cost of solar panels fell by about 30% and the cost of the solar power system fell by more than 15% in 2023[35]. Construction and land costs are likely to remain the same or slightly increase, therefore we estimate that the total project costs fell by about 10% in 2023 and will continue to fall by 3-6% in 2024.

- We assume that the project cost of onshore wind fell by 5-10% in 2023 and 3-6% in 2024[36]. For offshore wind, we assume that the project cost fell by more than 10% in 2023 and 4-6% in 2024.

- Project cost of battery energy storage solutions (BESS) fell materially in 2023 in China. We assume that the total project cost of BESS fell by 30% in 2023 and 10% in 2024[37].

Figure 13 illustrates the results of LCOE for different technologies. Detailed assumptions are provided in Appendix B.

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[35] Su, N. (2024) 光伏产业今年将有"激战".
http://paper.people.com.cn/zgnyb/html/2024-03/04/content_26045928.htm.

[36] These are based on WaterRock Energy's internal data-base. The cost reduction could be higher than our estimates, partly because wind equipment suppliers may sell at a loss. For example, based on the renewable energy engineering cost management report 2023 from China Renewable Energy Engineering Institute, total project cost was down by 22% for onshore wind.

[37] These are based on WaterRock Energy's internal database. The cost reduction could be higher than our estimates, partly because BESS may sell at a loss. For example, based on the 2024 BESS white paper from China Energy Storage Association, the cost of BESS fell by more than 50% in 2023.

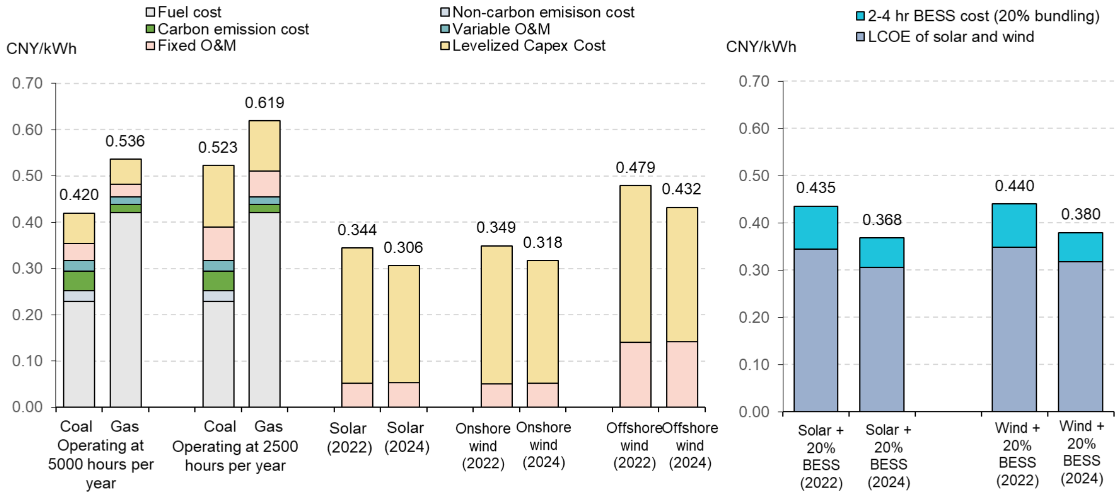

Figure 13 | Cost comparison of thermal plants versus wind/solar (average)

Note: The methodology of LCOE calculation is provided in Appendix A of the *2023 power shortages report*. A carbon tax of CNY 40/metric tonne is used. 50% of the 2-4 hour BESS cost is recovered from the ancillary service market and the other 50% is recovered from the energy market. Our costs do not include value added tax.

Source: WaterRock Energy research and analysis.

Comparing LCOE values suggests that solar and wind power are significantly more cost-effective than coal and gas, with the cost gap widening notably over the past two years.

- Without considering the carbon emission cost, the LCOE for new utility-scale solar and wind projects is about 10% cheaper than the new coal projects in China in 2022. With the material cost reduction in 2023 and 2024, the cost savings have increased to about 20% for solar projects and 16% for wind projects.
- Bundling solar and wind capacity with 20% of 2-4 hour BESS can help to address the wind and solar intermittency issues and shift some of the solar and wind energy generation to peak hours. In 2022, the total cost of solar plus BESS or wind plus BESS is slightly higher than coal. With material cost reduction in 2023 and 2024, the total cost with 20% BESS bundling is about 10% cheaper than building new coal projects.
- Assuming a carbon emission cost of CNY 40/tonne-CO_2, the cost saving for building solar/wind versus coal projects is increased by about 8%.

Chapter 4.3.1 provides a more detailed analysis to show that renewable exports from Inner Mongolia are more cost-competitive than local resources in the receiving provinces and renewable exports from neighbouring inland provinces.

4.2.2 Evolving transmission technology

Transmission technology has evolved quickly in the past decade. The development of VSC HVDC technology in recent years has enabled the transfer of bulk variable renewable power from remote resources with weak grid areas to load centres.

The VSC HVDC technology has superior control with regards to integrating volatile renewable generation and stabilising AC networks[38]. It can improve reliability, resilience, and power quality, such as for:

- dynamic voltage control;
- fault recovery;
- AC grid oscillation damping, grid harmonics filtering, and phase balancing; and
- frequency regulation, black start, and system restoration in coordination with neighbouring power systems or connected resources.

VSC HVDC technology can also provide power flow control and AC grid congestion management, including through mitigation of AC contingency and stability constraints (thereby increasing the transfer capability of the existing AC grid, particularly in systems with high numbers of inverter-based generating resources); and it has the ability to support weak AC grids, such as through grid forming operations, and high-density load centres through undergrounding options and fault current mitigation[38].

Multiple international studies have identified significant amounts of VSC HVDC transmission as a cost-effective option for high-renewable-generation futures, as discussed in TenneT's Dutch-German 'Target Grid' case study in Appendix A.1 and also in several recent publications[39,40,41,42].

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[38] Pfeifenberger, J.P., Plet, C.A., Bai, L., Levitt, A., and Sonnathi, C.M. (2023) The operational and market benefits of HVDC to system operators. https://acore.org/resources/the-operational-and-market-benefits-of-hvdc-to-system-operators/.

[39] Bloom, A., Novacheck, J., Brinkman, G., and others (2021) The value of increased HVDC capacity between eastern and western US grids: The interconnections seam study. IEEE Transactions on Power Systems, 37(3), 1760-1769. https://ieeexplore.ieee.org/document/9548789.

[40] NREL (2020) Interconnection Seams Study. https://www.nrel.gov/analysis/seams.html.

[41] NRE (2021) The North American Renewable Integration Study. https://www.nrel.gov/analysis/naris.html.

[42] Energy Systems Integration Group (2022) Design Study Requirements for a U.S. Macrogrid: A Path to

In China, several VSC HVDC lines have been built. For example, the ±500 kV HVDC VSC ZhangBei line has helped to export a high share of intermittent wind and solar generation from clean energy bases in Zhangjiakou and Chengde to Beijing and Tianjin. Therefore, we suggest that China can adopt the new VSC transmission technology to ensure the bulk of the renewable energy transfer from new clean energy bases to the load centres.

4.2.3 The long-term strategic value of producing green fuels

For the clean energy bases in Inner Mongolia, green power can be channelled to produce green fuels, such as green hydrogen or green ammonia. Green fuels can be used in non-power sectors, such as shipping fuels. This provides a long-term strategic value to develop a green fuel value chain in Inner Mongolia.

Inner Mongolia is also actively pursuing a strategy to position itself as one of the main green fuel (such as hydrogen) production hubs in China. On May 30, 2024, the Inner Mongolia government released a document to push forward the hydrogen industry in the area[43]. The announcement encourages the planning of green hydrogen production in new large renewable bases. Inner Mongolia is also planning to build a hydrogen pipeline to export hydrogen to Beijing, Tianjin, Hebei and Shandong.

4.3 Economic analysis

4.3.1 Economics of large-scale clean energy bases

As discussed in Chapter 4.1.1, the Inner Mongolia government has planned to build several clean energy bases, aiming to help increase the utilisation rates and the renewable share of those existing UHV lines.

Inner Mongolia has two key advantages for large-scale renewable power exports:

- A large part of Inner Mongolia is closer to load centres in North China and East China than most provinces in the northwest, such as Qinghai, Gansu and Xinjiang.

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achieving the Nation’s Energy System Transformation Goals. https://www.esig.energy/technical-studies-to-design-transmission-expansion-for-a-clean-electricity-future/.

[43] Inner Mongolia People's Government (2024) 关于进一步加快推动氢能产业高质量发展的通知. https://h2.in-en.com/html/h2-2437111.shtml.

- It has a large amount of available land with good wind and solar resources to build large-scale clean energy bases. Most of the projects are built in deserts or on land that is unsuited to cultivation and therefore does not compete with agricultural land use. The local renewable power market prices have been only traded at CNY 0.22-0.30/kWh, indicating that they are more cost competitive than many inland provinces, like Shanxi and Shaanxi.

Figure 13 provides a comparison of the cost of exporting renewables to Hebei based on the existing UHV lines. Among renewable sources from neighbouring inland provinces, renewable sources from Inner Mongolia are the most competitive, with prices at about CNY 0.39/kWh in the receiving provinces.

Furthermore, in the load centres in North, East and Central China, the average power tariffs have been at CNY 0.41-0.50/kWh in recent years, so the total cost of renewable sources from Inner Mongolia can also help to save cost for the end users in the receiving provinces (see Figure 15). A deregulated market for inter-provincial power flow also implies that Inner Mongolia renewable sources could bid at higher prices to export to load centres in North China.

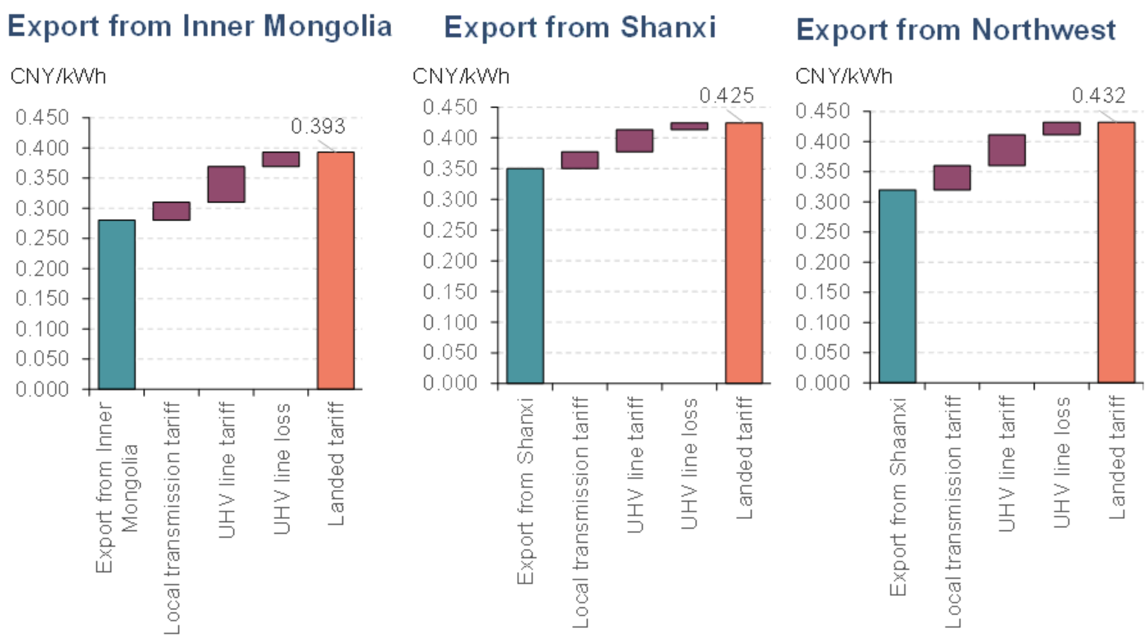

Figure 14 | Comparison of power exports from large-scale clean energy bases to Hebei

Note: For RE exports from Inner Mongolia, the average RE tariff is about CNY 0.28/kWh based on 2023 trading data, the local transmission tariff is CNY 0.03/kWh, the UHV line tariff is CNY 0.05895/kWh and the UHV line loss is 6.5% based on Shanghaimiao-Shandong UHV DC line. For RE exports from Shanxi, the average RE tariff is about CNY

0.35/kWh based on 2023 trading data, the local transmission tariff is CNY 0.027/kWh, the UHV line tariff is CNY 0.036/KWh and the UHV transmission loss is 2.77% based on Jibei-Jiangsu UHV line. For RE exports from Shaanxi, the average RE tariff is assumed to be CNY 0.32/kWh, local transmission tariff is CNY 0.04/kWh, UHV transmission tariff is CNY 0.051/kWh and UHV line transmission loss is 5.0% based on Shaanxi-Hubei UHV DC line.

Source: WaterRock Energy analysis based on data from NDRC, NEA and public news.

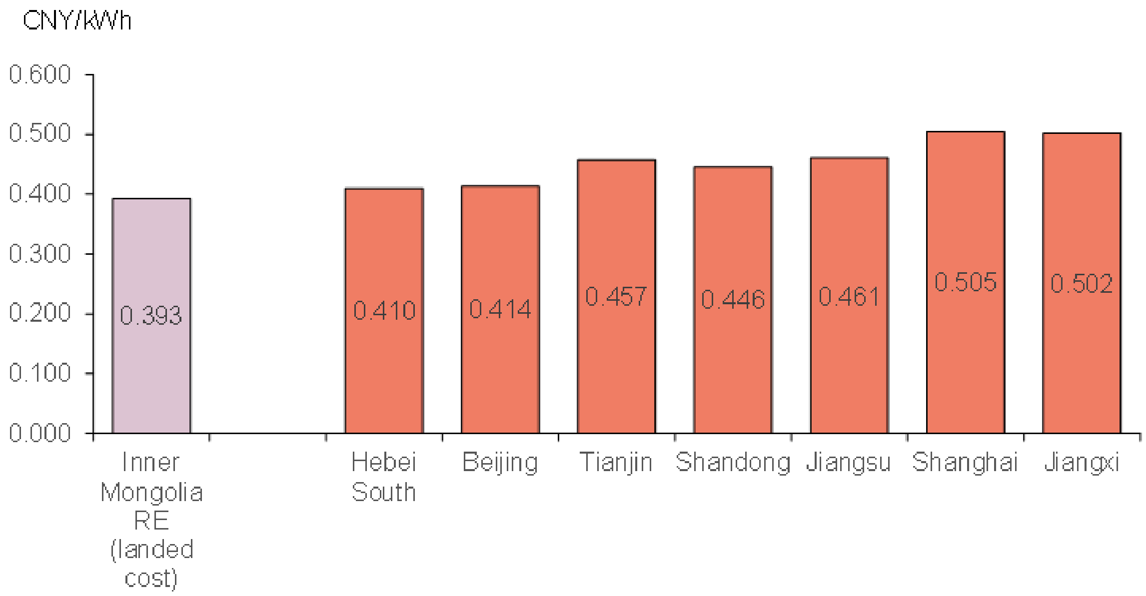

Figure 15 | Comparison of the total cost of Inner Mongolia RE arriving in the receiving provinces and average 2023 local market prices of receiving provinces

Note: The average market prices of receiving provinces are based on their third-party grid purchase prices (电网代购电价) in 2023.

Source: WaterRock Energy analysis based on data from provincial grid companies

4.3.2 Economics of building new coal-fired power plants for a supporting role

Four large 'Sha-Ge-Huang' bases are being built in Inner Mongolia, each of which will have 4 GW of coal-fired power to support 8 GW of solar and 4 GW wind energy bases. Detailed technical and economic studies need be carried out to evaluate the necessity of the 4 GW new coal-fired power projects.

In a local system with a large amount of solar and wind capacity, the supporting capacity will need to start up and shut down frequently and be able to ramp up or down quickly to provide a supporting role. It is questionable whether the technical characteristics of coal-fired power plants are most suitable for such system needs. Based on the typical hourly generation profile of 8 GW solar and 4 GW wind projects in Inner Mongolia, the supporting dispatchable coal capacity will likely need to shut down around noon and then quickly start up and ramp up in late afternoon, evening and night time (Figure 14). The operational characteristics of coal plants are not suitable for frequent cycling.

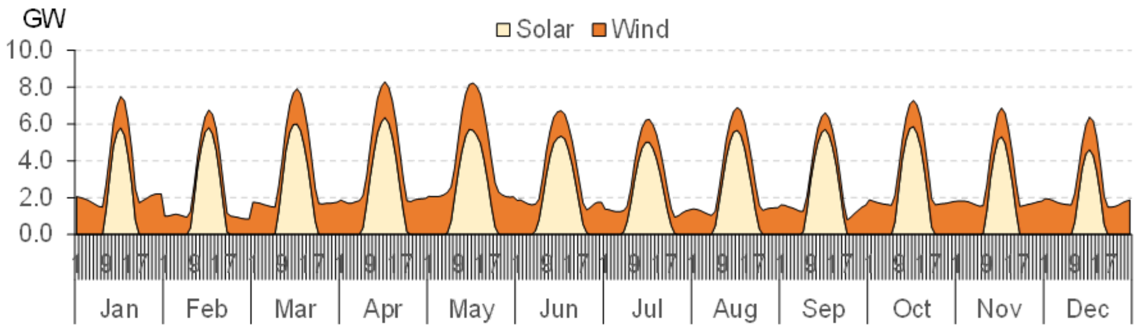

Figure 16 | Average hourly generation profile of 8 GW solar and 4 GW wind in Inner Mongolia

Source: WaterRock Energy analysis based on data from https://www.renewables.ninja/

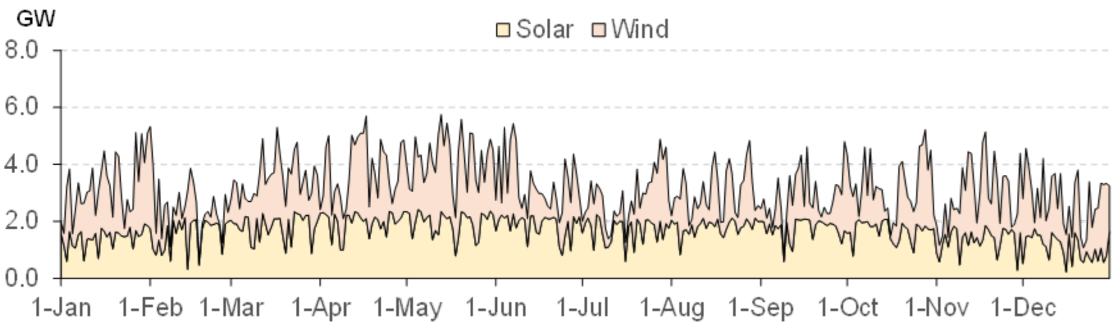

Figure 17 | Average daily generation of 8 GW solar and 4 GW wind in Inner Mongolia

Source: WaterRock Energy analysis based on data from https://www.renewables.ninja/

Based on the daily generation profile (see Figure 16 and Figure 17), the seasonal variations of the proposed clean energy bases does not seem to fluctuate significantly. This implies that the main challenge is to deal with the intermittency of the hourly generation within a 24-hour period. The most suitable flexible resources are battery energy storage capacity and demand response from the local grid and the importing provinces, as discussed in Chapter 5.1.1 of the *2023 power shortages report*.

Furthermore, studies should be done to understand how to build up local 500 KV and 220 KV transmission lines to tap into the existing generation sources in Inner Mongolia for the supporting role rather than building new coal-fired power capacity.

In the two international case studies discussed in Appendix A, TenneT's Dutch-German Target Grid and Terna's Italian Hypergrid projects propose to build large renewable bases, and there is no need to build supporting thermal capacity for those projects. As discussed in Chapter 4.2.2, the VSC HVDC transmission technology is adopted in grid infrastructure to enable moving bulk variable renewable power from remote resource areas with weak areas of the grid to load centres.

5 Policy-relevant insights

5.1 Investment

5.1.1 Accelerating the investment in associated clean energy bases for existing UHV lines

The utilisation rates and renewable shares of the five existing UHV lines in Inner Mongolia are both still less than 40% (see Chapter 3.1). Renewable exports from large-scale clean energy bases in Inner Mongolia to the load centres are more cost-competitive than those from most other inland provinces and/or using local resources in the load centres (see Chapter 4.3.1). Thus, investment in the associated clean energy bases should be pushed ahead and even accelerated. Studies can also be done to analyse whether additional clean energy bases could fully utilise the existing UHV lines.

Regulatory changes, such as allowing multi-year green corporate PPAs, are crucial to facilitate the economic expansion of clean energy bases. These changes need to be implemented swiftly to ensure the continued growth of the clean energy sector.

5.1.2 Pushing forward the new UHV lines and new 'Sha-Ge-Huang' clean energy bases

As discussed in Chapter 4.1.2, several new 'Sha-Ge-Huang' large-scale clean energy bases are planned in Inner Mongolia, and each also plans a new UHV line to export green energy out of Inner Mongolia. These projects should be pushed forward. Based on the lessons learned from the existing clean energy projects, the construction of physical generation and transmission projects needs to be carefully coordinated so that the bottlenecks for any specific segment do not lead to the under-utilisation of all the assets.

The new UHV lines should also utilise the latest transmission technologies, such as VSC HVDC technologies, so as to enable the export of a large share of variable renewable energy without causing reliability issues in the sending and receiving provinces.

Furthermore, when planning for the new large-scale clean energy bases, the long-term strategic value of using green power to produce green fuels should be considered.

5.1.3 Limiting associated coal capacity expansion for the large-scale clean energy bases

The government needs to take immediate action to limit the ongoing expansion of coal capacity associated with the large-scale clean energy base. Adding new coal capacity may not be the appropriate solution to help provide 'stable' and 'firm' export volume. The relatively high daily start-up and shut-down cost, and slow ramp rate of coal plants are not aligned with the real need to bundle large amounts of solar and wind to export 'stable' volumes to other provinces. Priority should be given to incentivising investment in more flexible capacities, such as battery energy storage, pumped hydro storage, open cycle gas units, concentrated solar plants, and demand response solutions in both sending and receiving provinces.

Even if coal capacity is required as a long-term backup capacity for situations in which there is a prolonged period of low renewable-power generation, the focus should be on investigating how to retrofit the existing coal fleet to enable them to serve such a purpose.

5.2 Inter-provincial trading

Enhancing power market trading across different provinces is a complex task that requires careful management of benefits and costs. Taking incremental steps to gradually improve this process is a practical and effective way forward.

For inter-provincial trading between Inner Mongolia and other provinces, incremental enhancements can be provided for more flexible short-term trading and multi-year green PPAs. Regular short-term and spot market trading should be organised to utilise any available transmission capacity fully. Several enhancements can help to increase the liquidity of short-term trading:

- The legacy contractual arrangement between dedicated generation projects and receiving provinces, based on dedicated physical power flow, can be converted to contract-for-difference (CfD) financial contracts. This shift would increase contractual flexibility and allow more economic power flow when short-term market conditions change.
- Regular annual, monthly and multi-day trading for inter-provincial power flows can be provided in the Beijing and Guangzhou power exchanges, similar to the local trading systems already in place in many provinces across China.

- The current inter-provincial transmission tariff is based on per kWh, and all the costs are typically paid by the receiving provinces. Shifting the per kWh inter-provincial transmission tariff to two-part pricing with a capacity charge set up for recovery of CAPEX of transmission assets should be considered. If a capacity charge is adopted to recover the CAPEX of the inter-provincial transmission line, it should be able to help to better optimise short-term power flows across different provinces economically, as the short-term price signal of power imports will include the short-run variable cost of the power plants at the sending end plus the short-run variable cost of using the transmission line plus transmission loss. This should be able to provide overall system cost savings.
- Mengxi currently has a spot wholesale electricity market and some of the receiving provinces, for example, Shandong, also have a spot wholesale electricity market. Studies can be done to see how best to link those two spot wholesale markets to facilitate the economic day-ahead unit commitment and real-time power flow across the two markets. Experience and lessons learned can then be applied to link Inner Mongolia to the other receiving provinces through day-ahead and spot electricity market trading.

Furthermore, local governments should allow direct multi-year green PPA between RE developers in the large-scale clean energy bases in Inner Mongolia and the large end-users in the receiving provinces. The formal signing of such direct bilateral contracts can be organised regularly, as has been done for annual normal bilateral contracts in the West Inner Mongolia (Mengxi) market. There are several benefits for allowing direct multi-year green PPAs:

- The direct multi-year green PPAs can increase the bankability of the large-scale clean energy bases;
- They can help to reduce price volatilities for both the RE developers and large end-users;
- The market-based direct negotiation should be able to help the RE developers to fully realise all the value streams of the large-scale clean energy bases, such as the green attributes for new projects; and
- Market-based contracts can better reflect the market fundamentals in the sending provinces and receiving provinces, which can then help to ensure economic power flow across the different provinces.

5.3 Engaging all relevant stakeholders

Building large-scale clean energy bases for local consumption and exports is a collective effort that involves multiple stakeholders, including provincial governments at the sending and receiving ends, provincial and regional grid companies, generators, retailers and end-users at the sending and receiving ends. Therefore, coordination and engagement with different stakeholders are not just important but essential for the success of energy transition.

For the large 'Sha-Ge-Huang' clean-energy bases, new UHV lines for export need to be built. This will require coordination with the importing provinces on both long-term system planning and short-term operational details.

- For long-term system planning, Inner Mongolia needs to engage with importing provinces to ensure that they reflect the planned power imports in their system planning. This can prevent the importing provinces from planning to over-build their expensive local power fleets, such as local new coal capacity.
- For short-term operational details, mechanisms and cost allocations for co-sharing resources such as peaking capacity to deal with renewable intermittency and local system emergencies across provinces should be studied and agreed upon.

6 Concluding remarks

Inner Mongolia is currently China's biggest renewables producer and power exporter. It has been operating five UHV lines, although their utilisation rates have been less than 40%, and the annual renewable share for the exports through UHV lines has been lower than 40%.

With its abundant wind and solar resources, Inner Mongolia is in an excellent position to help China accelerate its pace of decarbonising the power sector. The expansion of large-scale clean energy bases in arid, desert, and barren regions not only optimises 'unused' land but also generates substantial revenue streams for local governments, painting a promising picture for the future of renewable energy in China.

The pace of the construction of the 27 GW new large-scale clean energy bases, which can tap into the existing UHV lines, should be accelerated. Commissioning large-scale clean energy bases is crucial to increase the utilisation rate of the existing UHV lines and boost the green export volumes for major end-users in the receiving provinces.

The areas in which the four planned "Sha-Ge-Huang' clean energy bases (each of which will have 8 GW solar and 4 GW wind) all have weak local energy demand and grid infrastructure. Accelerating the approval and building of dedicated UHV DC lines and adopting the latest VSC HVDC transmission technologies for the planned 'Sha-Ge-Huang' clean energy bases will be necessary to avoid renewable curtailment issues and enable a high renewable share in the export volume. Careful coordination of project development for different segments is also essential to avoid any potential bottlenecks when developing those ambitious projects. Furthermore, the project developers and local government should seek to limit the planned new associated coal projects because coal is not the appropriate solution to provide support for exports with high renewable share. Instead, highly flexible capacity and solutions, such as BESS and demand response, should be adopted for both receiving and sending provinces.

As Inner Mongolia develops large-scale clean energy bases, inter-provincial power flow between Inner Mongolia and other provinces is expected to increase significantly and quickly in the future. A higher share of the power flow will be intermittent wind and solar sources, resulting in increasing short-term operational complexities. We recommend enhancing the trading arrangements through measures that include:

- provision of regular annual, monthly and multi-day trading for inter-provincial power flows in the power exchanges, similar to that with local trading within the respective provinces in most provinces in China.

- explore ways to link up the day-ahead and real-time spot wholesale electricity markets in Mengxi and Shandong and then expand it to other provinces.

Moreover, multi-year direct long-term PPAs between RE developers and large corporations in receiving provinces should be allowed and facilitated. This could help increase the bankability of the large energy bases, reduce price volatility, and fully reflect the market value of green attributes of new solar and wind projects.

China is moving in the right direction to achieve its dual carbon targets. As the pace of building new solar and wind capacity accelerates and the large, clean energy bases associated with UHV lines and other projects are built in inland provinces, the power system will become increasingly complicated. Inter-provincial power flow will become more important to ensure supply adequacy and to meet green consumption targets in different provinces. Thus, increasing grid flexibility and setting up a market structure to incentivise appropriate investment and operation for inter-provincial power flow could bring significant benefits to the power system and the economy. Furthermore, new generation and transmission technologies will continue to emerge. All the key stakeholders in the power sector could capitalise on these trends to peak China's carbon emissions before 2030 and achieve carbon net zero before 2060.

Appendix A: International case studies

China is not the only country that plans to build long-distance ultra-high or high-voltage lines to transfer green power from good renewable resource areas to load centres. Many other countries and regions are already doing or planning to do the same. We provide two case studies in Europe: TenneT's Dutch-German Target Grid; and Italian firm Terna's Hypergrid.

Key takeaways from the international case studies include:

- The planning and building phases of grid-related infrastructure are the most important and challenging parts of the project. VSC HVDC technologies are deployed in the two case studies.
- Significant time and financial investments are required for renewable energy infrastructure projects. Standardisation of transmission components along the value chain could help to save costs over time.

A.1 TenneT's Dutch-German Target Grid

In April 2023, the Dutch electricity transmission system operator TenneT proposed a Target Grid with a vision of an integrated, onshore and offshore, cross-border electricity grid in Europe[44]. Target Grid will be a network of high-capacity AC and HVDC transmission lines and energy hubs to transport green power from the wind-rich North Sea to consumers and industry while maintaining a reliable electricity grid. The company says it aims to "make it possible for the North Sea to become a genuinely sustainable green hub for the supply of electrons at the heart of the European energy transition".

[44] TenneT presents Target Grid, its vision for the electricity grid of 2045, April 14, 2023 at https://www.tennet.eu/news/tennet-presents-target-grid-its-vision-electricity-grid-2045.

Figure 18 | TenneT's Target Grid

Source: https://www.tennet.eu/news/tennet-presents-target-grid-its-vision-electricity-grid-2045

TenneT plans to deploy HVDC transmission technology to move power from large-scale offshore wind farms in the North Sea to the load centres in Europe. It is envisioned to deliver 18 GW by 2030 and then 40 GW in the long term. It is currently implementing a 2GW Program[45], and new standards set in the 2GW Program can be replicated in every part of the supply chain for future expansion. The standardisation of transmission components should be able to reduce the project costs over time.

Under the 2GW Program, TenneT is deploying a new VSC technology. It is the only HVDC option capable of integrating offshore wind generation, providing high-capacity connections at weak portions of the AC grid in northern Germany, and offering operations in grid-forming mode[46].

A.2 Terna's Italian Hypergrid

Terna is the operator of the Italian transmission grid and is the largest independent electricity

[45] Details can be found in https://www.tennet.eu/about-tennet/innovations/2gw-program (access on 29 July 2024).

[46] See page 91 of the Brattle and DNV report 'The operational and market benefits of HVDC to system operators'.

transmission system operator (TSO) in Europe. It announced plans to develop a €11 billion Hypergrid in its 2023 National Electricity Grid Development Plan[47], which is part of a €30 billion long-term grid modernisation plan (of which €21 billion will be invested in the next 10 years)[48].

The Hypergrid plan consists of 30 strategic transmission infrastructure projects to meet Italian and European decarbonisation targets (Figure 16). Terna will leverage HVDC transmission technologies to enhance the capability of the existing lines where possible to minimise environmental impacts and double the power that can be transmitted from renewable generation in Southern Italy to high-load areas in the North (from today's 16 GW to more than 30 GW) over the next 15 years[49]. It will also enable the development and integration of renewable generation to meet the country's renewable generation target of 85 GW by 2030 announced by Minister Gilberto Pichetto Fratin[50].

Figure 19 | Terna's Italian Hypergrid

Source: Terna, Terna: 2023 Development Plan for the National Electricity Grid Presented, Press Release, March 15, 2023 at https://www.terna.it/en/media/press-releases/detail/2023-development-plan.

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[47] Terna, Terna: 2023 Development Plan for the National Electricity Grid Presented, Press Release, March 15, 2023 at https://www.terna.it/en/media/press-releases/detail/2023-development-plan.

[48] Terna Spa, Terna: 2023 Development Plan for the national electricity grid presented, Press Release, March 15, 2023 at https://www.terna.it/en/media/press-releases/detail/2023-development-plan.

[49] Ibid.; and Terna, Terna and the Sicilian Region: 2023-2032 National Electricity Grid Development Plan meeting, Press Release, March 30, 2023 at https://www.terna.it/en/media/press-releases/detail/meeting-sicilian-region-national-electricity-grid-development-plan.

[50] G. Navach and F. Landini, 'Terna to invest over 21 bln euros in Italy power grid in 10 years *Reuters*,' March 15, 2023 at https://www.reuters.com/business/energy/terna-invest-over-21-bln-euros-italy-power-grid-10-years-2023-03-15/.

Appendix B: Assumptions for the LCOE calculation

Table 2 provides a summary of key cost assumptions of the representative thermal, solar and wind plants for our cost-competitiveness analysis in China.

Table 2 | Key assumptions for the thermal, solar and wind plants in China, nominal term

	Unit	New USC coal plant	New CCGT	Utility-scale solar	Onshore wind	Offshore wind
Total CAPEX	CNY/kW	3800	3108	4294 (2022) 3726(2024)	6824 (2022) 6092 (2024)	10573 (2022) 9040 (2024)
After-Tax WACC (ATWACC)	-	5.6%	5.6%	5.6%	5.6%	5.6%
Corporate Tax Rate	-	25%	25%	25%	25%	25%
Economic life	Year	25	25	25	20	20
Capital recovery cost*	CNY/kW-year	332	271	375 (2022) 325 (2024)	656 (2022) 585 (2024)	1016 (2022), 868 (2024)
FOM	CNY/kW-year	182	140	67 (2022) 68 (2024)	111 (2022) 113 (2024)	422 (2022) 427 (2024)
VOM	CNY/kWh	0.023	0.016	-	-	-
Net HHV heat rate**	GJ/MWh	9.0	6.9	-	-	-
Fuel cost	CNY/GJ	24.8	61.3	-	-	-
Non-carbon emissions treatment cost	CNY/kWh	0.023	0	-	-	-
Availability factor	-	Assumed to run 5000 hours for base-load application and 2500 hours for mid-merit application		Average 15% (or 1285 hours)	Average 25% (or 2198 hours)	Average 34% (or 3000 hours)

*Note: Details of different items and calculation of the levelized cost of energy (LCOE) is discussed in Appendix A of the *2023 power shortages report*.

**We use the typical practice in Asia and quote net high heat value heat rate.

Source: WaterRock Energy estimates and analysis.

Abbreviations

AC	alternating current
ATWACC	after-tax weighted-average cost of capital
BESS	battery energy storage solution
CAGR	compounded average growth rate
CAPEX	Capital Expenditure
CEC	China Electric Council
CfD	contract-for-difference
CNY	Chinese Yuan
CO2	carbon dioxide
CREA	Centre for Research on Energy and Clean Air
DC	direct current
EU	Europe Union
FYP	Five-Year Plan
GEC	green energy certificate
GW	gigawatts
HV	high voltage
HVDC	high-voltage direct current

IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCOE	levelized cost of energy
NDRC	National Development and Reform Commission (China)
NEA	National Energy Administration (China)
NEM	National Energy Market
O&M	Operation and Maintenance
PJM	Pennsylvania-New Jersey-Maryland
PPA	power purchase agreement
RAP	Regulatory Assistance Project
RE	renewable energy
TW	terawatt
TWh	terawatt-hour
UHV	ultra-high voltage
US	United States
USC	ultra-supercritical
USD	US dollar
VSC	voltage-sourced converter