Power system adequacy and "New Power System" development in China

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Executive summary

China has pledged to peak carbon emissions by 2030 and achieve carbon neutrality by 2060, which has set a long-term goal for reducing emissions. The total amount and intensity of carbon emissions are important constraints on structural changes in the power sector. The pathway to efficiently drive the transition in the energy system is the next key issue. Climate research suggests that the power sector is the industry with the most available options for emissions reduction technologies, therefore it should be the first to achieve decarbonization and eventually (near) zero emissions.

Several severe power outages occurred globally during 2020 and 2021. The issue of power system adequacy, especially outages caused by increasingly frequent extreme weather events, has become a focus of governance as well as being a concern to the general public.

Targets set by the Chinese government to push for the establishment of a new power system include those to: deepen the reform of the power system; build a system dominated with new energy; and accelerate the development of a national unified power trading market.

In this report, we analyse a series of power outage events in 2020 and 2021 with a focus on system capacity adequacy followed by a discussion on how a novel power system could be established. We also evaluate the system adequacy of East China (during summer) and Central China (during winter) based on available generation resources and projected maximum demand.

The contents of this report include:

- A description and explanation of the power outages in Texas, United States; Hunan and Jiangxi, China; and Western Europe. We also share our opinions on the roles of various power sources and the interpretation of system adequacy.
- A summary of China's current dispatching paradigm of the power system, focusing on the institutional obstacles that negatively impact the improvement of the power system efficiency. Based on such observations, this report also provides insights for a novel power system.
- Case study: East China, Summer 2021. This report evaluates the system capacity adequacy of each province in East China and the overall region, plus the contribution of various power sources and possible extreme scenarios given fluctuating energy demand.

- Case study: Central China, Winter 2021. This report evaluates the level of system adequacy in Central China (using the same methodology that was applied to assess East China), and discusses the approach to reduce the need for redundant units through more flexible operations, even under extreme climate conditions.

- Conclusion and suggestions. Based on the case studies and analyses, this report summarises the key challenges for China to meet its long-term goal to achieve zero emissions in the power sector, and proposes policy recommendations.

This report concludes that:

- The East China case study shows that if the scope of balancing expands from the provincial level to the regional level, it is possible to avoid the need to expand capacity of more than 30GW, and save about 90 billion Yuan, or 13.5 billion USD, in infrastructure investment. With balancing on a larger geographic scale than is used at present, there will be no problem in system adequacy over the next 5 years. Even under various adverse conditions (demand beyond projection, outage of inter-regional transmissions, decreased solar output), the system would still remain robust.

- The Central China case study shows that power generation resources in all provinces are sufficient. Most of the new power demand can be smoothed through flexible cross-province operation within the regional grid. As the energy demand in some of the provinces increasingly peaks in the winter, cross-provincial balancing will be complementary across provinces and could reduce 11% of projected total power installations.

- Adding new fossil energy units goes against the roadmap towards meeting climate targets and economic rationality. New coal power plants would mean a negative shift in the carbon emissions trajectory of the power sector in upcoming years, or would require carbon capture, utilisation and storage (CCUS), whose prospects are still highly uncertain. The duration of surging electricity demand tends to be on a short-term basis, which is not suitable for coal-fired power plants because coal plants usually need an operational period of more than 4,000 hours per year to be economical.

- Novel power systems should be highly flexible and intelligent. Annual monitoring and assessment of adequacy and transparency should be required. To ensure adequacy in an economical manner, it is necessary to make investments to strengthen power grids that are below 500kV, and also lay a physical infrastructure foundation to support a regional cross-province balancing as well as the unified power market.

Note regarding fuel supply: Without a significant proportion of solar and wind in the energy mix, power outages will be severe if there is a fossil-fuel shortage. Often, the risks of fuel shortages are

not included in the assessment of system capacity adequacy and reliability, therefore this report does not focus on fuel supply issues.

Glossary

Term	Explanation
Capacity adequacy	There is sufficient capacity available in the power system to meet demand at all times.
Energy transition	Structural changes in the energy system, mainly referring to the transition to renewable energy from fossil energy. The term also encompasses related technical, economic, policy and political issues.
Projected peak demand	Power system peak demand under some certain probability, measured as kW.
System flexibility	The ability of the system to remain balanced in the face of various uncertainties. In the context of the increasing share of wind and solar, the flexibility often focuses on the start-stop time, ramp rate and minimum output of fossil-fuel units.
Balancing resolution / granularity	A measure of the level of detail in the discrete unit-commitment of the system, such as determining the output level based on day, hour, 15-minute or 5-minute intervals.
Economic efficiency	The use and distribution of each scarce resource in the economy between producers and consumers yields the greatest economic output and surplus. Considering only the supply side, economic efficiency is equivalent to maximising profits/minimising costs; considering only the consumption side, it is equivalent to maximising welfare.

1. Analysis of power outage incidents and the limitations of the current power system

1.1 Frequent extreme weather incidents call for a robust, responsive power system

Changes to the global climate as a result of increased greenhouse gas emissions from burning fossil fuels has led to increased global average temperatures and increased frequency and intensity of extreme weather events in some regions. It is important to note that it is not possible to attribute extreme weather events to one cause, because there is an element of natural climate variability in weather events, according to the International Panel on Climate Change[1]. Fluctuations in the electricity demand in the past few years have been a test for how the power system might respond in future decades. In this chapter, case studies to illustrate power outage events in different global locations illustrate how the power system is insufficiently prepared to respond to the future trends of climate change.

Case study: the United States In mid-February 2021, Texas, US, experienced a week-long power outage. The main reason was the shortage of fuel due to an impaired supply chain. Additionally, soaring energy demands were caused by cold weather and the lack of low-temperature resistance in the main energy infrastructure. The output of natural gas units was significantly lower than the nameplate capacity due to the fuel shortage, and exacerbated by the decline in output from other power sources[2].

Texas was not unprepared. On September 3, 2020, at the 9th Winter Generator Weather Symposium organised by Texas Reliability Entity, Inc. (TexasRE) and the Electric Reliability Commission of Texas (ERCOT), plant operators presented their experiences with recent extreme weather events and covered lessons learned, best practices, and exchanges of reliability improvements[3]. Before this crisis, ERCOT's capacity reserve was expected to be 15.5%[4]. This is not a low figure under normal circumstances. However, the output capacity declined far more than previously expected during extreme weather events.

[1] https://www.ipcc.ch/site/assets/uploads/2018/03/SREX-Chap3_FINAL-1.pdf

[2] Federal Energy Regulatory Commission (FERC) eventually published the incident report on 2021/11: https://www.ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and

[3] https://www.ercot.com/calendar/event?id=1595350520077http://www.ercot.com/committees/workshops/2020

[4] https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/121620-ercot-sees-155-reserve-margin-up-from-2020s-126-down-from-may-forecast

Case study: Europe On January 8, 2021, a short-term breakdown of the power grids in southern, central and western Europe, left 200,000 households with no power supply. The accident originated from an equipment failure problem in Croatia. The weather at the time was part of the cause. At that time, southern Europe was in the midst of a religious holiday, with mild weather and low demand for electricity, while central and western Europe had high electricity demand due to cold weather. The grid section flow between them was much larger than usual, leading to a short-term spike in frequency fluctuations.

Case study: China Between the end of 2020 and mid-January 2021, Hunan and Jiangxi implemented load shedding. Some industrial and commercial enterprises in Changsha City, Hunan Province, were required to reduce the load or shift the peak for production. The local government also stipulated that "the air conditioner should be turned off" in offices during the day. According to the National Development and Reform Commission (NDRC), the reasons for reducing the power supply were: the rapid growth of industrial power consumption; the need for increased load in extremely cold weather; the limitation of external power supply; and equipment failure[5]. The interpretation was on a national scale. On December 14, 16 and 30, 2020, and January 7, 2021, the national highest dispatched load hit a record high four times. On the evening of January 7, the peak load reached 1.19 billion kilowatts and the daily power generation capacity was 25.97 billion kWh[6].

Global climate trends There is a global trend of increasing frequency of extreme weather events such as heat waves or low temperatures. The National Centre for Environmental Information of the United States reported that in 2020, the US experienced 22 major natural disasters, whereas the annual average from 1980 to 2020 was 7 major national disasters. From late June to early July 2021, North America experienced a week-long heat wave in large cities that rarely experience extreme heat, such as Portland, Seattle and Vancouver. In Columbia, Canada, 180 wildfires were recorded, with the highest temperature reaching a record high of 50℃. On August 11, 2021, the island of Sicily, Italy, experienced a high temperature of 48.8℃, one of the highest temperatures recorded in Europe. In North China, which is traditionally dry, the phenomenon of rainy weather in summer has become more frequent. In the summer of 2021, severe floods occurred in China, including in Henan, Shanxi, Sichuan, Guizhou and Chongqing.

During extreme weather events, the short-term surge in electricity demand and the risk of equipment failure will be an inevitable test for future power systems, and will be a reflection of how power system balancers respond to such events.

[5] http://www.xinhuanet.com/2020-12/17/c_1126874945.htm

[6] https://m.thepaper.cn/wifiKey_detail.jsp?contid=11607229&from=wifiKey

1.2 Ecological and environmental constraints on regional electricity planning

China has pledged to peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060. As part of this commitment, China will strictly limit the growth of coal consumption during the 14th Five-Year Plan period and gradually reduce coal consumption during the 15th Five-Year Plan period.

In addition, ecological and environmental governance is also affecting the industrial structure of the energy industry. For example, under the direction of the Action Plan for Air Pollution Prevention and Control and the Three Year Plan of Action for Winning the War to Protect Blue Skies, more than 100GW of outdated coal-fired power units have been phased out since 2013. In 2019, clean energy consumption accounted for 23.4% of China's energy mix, whereas the proportion of energy from installed coal-fired power units declined[7].

Traditionally, local governments usually rely on local capacity expansion to meet the need for power system adequacy. However, dependency on coal power usually makes it impossible to meet multiple energy development goals. The power outage in September 2021 is used by coal power lobbyists as an excuse of power supply shortage to support coal expansion – at least 7.3 GW of new coal projects were approved by authorities in the first six weeks of 2022[8].

However, it needs to be recognized that coal power projects are usually hard to advance under the constraints of carbon emissions regulations. Coal power is a key target for industrial structure optimization and the elimination of excess capacity. There have been many precedents for China's governmental interventions to stop and/or delay coal power projects[9],[10]. Air pollution, carbon dioxide emissions and water pollution have been cited by many studies as reasons to prioritise the decommission of coal power plants[11].

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[7] http://www.nea.gov.cn/2021-01/29/c_139707466.htm

[8] 《Boom & Bust 2022》. Global Energy Monitor. published on 2022/04. https://globalenergymonitor.org/wp-content/uploads/2022/04/BoomAndBustCoalPlants_2022_English.pdf

[9] *China National Energy Administration announcement on cancelling a batch of coal power project that does not meet criteria for permit or construction*. (《能源局关于取消一批不具备核准建设条件煤电项目的通知》). 2016/09. http://www.gov.cn/xinwen/2016-09/24/content_5111479.htm

[10] *Near a hundred of Shenhua's coal power projects shelved.*(《神华等近百个煤电项目缓建停建》). 2017/08. http://www.jlnyxx.com/nyzl/2017/0815/6315.html

[11] *A High Ambition Coal Phaseout in China: Feasible Strategies through a Comprehensive Plant-by-Plant Assessment, Center for Global Sustainability, University of Maryland.* https://cgs.umd.edu/research-impact/publications/high-ambition-coal-phaseout-china-feasible-strategies-through

Simply relying on capacity expansion, especially coal-fired power plants, to provide system adequacy will not meet the various goals for energy planning in the current era in which the goal is to reduce carbon emissions. As the proportion of fossil energy in the energy system continues to decrease, a power system that can adapt to this structural change will also be a premise to push for the energy transition and to achieve the targets set in the Paris Agreement.

1.3 Plans for the surging demands

In July 2021, China NDRC released its 'Announcement for Energy Sector Response to 2021 Summer Peak Demand' (NDRC 2021 Directive 1058) to prepare the scheduling. The announcement mentioned the phrase "supplying coal" more than 20 times.

Scheduling by releasing administrative orders is a less optimal approach because (1) it does not provide a way to prioritise among different solutions, and (2) we have observed similar announcements (e.g. in 2013, 2014 and 2019), which means it's a repeated request that should be addressed by the scheduling system, rather than through one-off manual schedule orders.

2. Outline a novel power system

Power systems require a constant supply of energy. Energy storage technology is not fully available at a large scale, which means that the power system is expected to be able to meet electricity demand at all times. This report focuses on power system adequacy, especially during the peak demand scenarios.

2.1 A power system with reliability, affordability and sustainability

Reliability, affordability and sustainability are the basic targets of a power system. To make improvements in these metrics, we sometimes implement 'Pareto improvement' such as demand-side response. In other scenarios, we choose trading off to increase performance on one or more specific factors.

One common approach to provide reliability is to deploy backup or reserve power generation sources for the system operator to schedule.

Improving the efficiency in operation and investment is a key approach to providing affordability. A temporal multi-layered trading market framework is a common entity established in the US and EU.

In this section, we first describe the common indicators for measuring power system adequacy, and then provide a general description of the system operation and scheduling paradigm in China. Then, by referring to and comparing the power dispatching models of selected European countries and the United States, we evaluate the attributes of China's current scheduling paradigm, with its impact on the system adequacy.

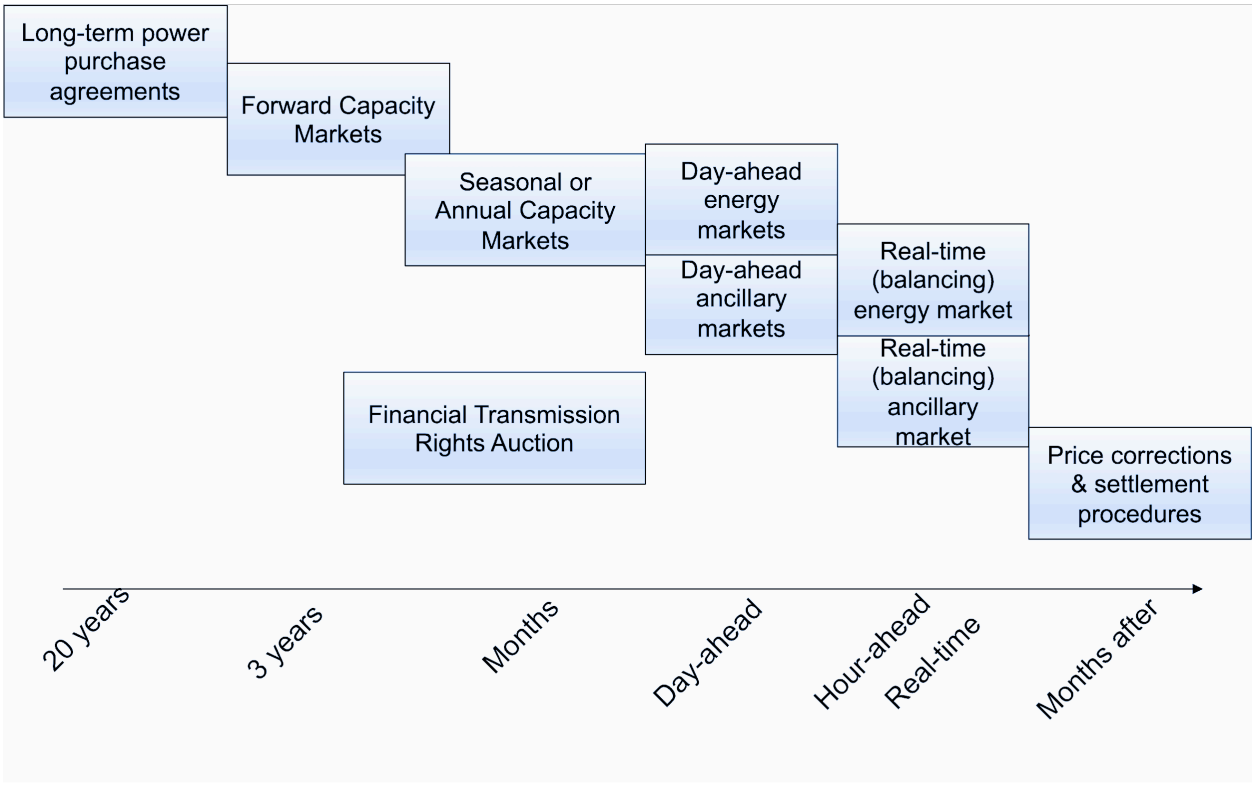

Fig 2-1 Multi-layered electricity trading market in different time scales.

Source: Erik Ela, UVIG workshop,https://www.esig.energy/event/2017-forecasting-workshop/

2.2 Criteria for system adequacy

Electricity generation adequacy is the most important factor in evaluating power system security. Usually, this is calculated by comparing the projected peak demand to the available generation resources. According to the 'Guide on Power System Safety' (GB 38755-2019): "*In order to ensure the stability of the power system operation ....., the system should have sufficient static stability reserves and active power and reactive power reserve capacity. Reserve should be allocated with reasonable capacity with necessary measures for adjustment*."

The 'Guide on Power System Safety' (GB 38755-2019) does not give a definition for what is "sufficient" or "reasonable" capacity. The 'Technical Regulations for Design of Electric Power System of the Ministry of Water Resources and Electric Power' (SDJ161-1985) suggests that the total system reserve should be at least 20%. The 'Power System Technical Guidelines', published in 2022, set standards that "*system backup capacity should be 2%~5% of peak load. Emergency backup capacity should be 10% of peak load, and not less than the single-stage capacity of the largest unit in the system or that fed into the maximum direct current (DC) capacity*", which was

reconfirmed in 'Measures for the Administration of Electric Power Reliability (Interim)' (NDRC 2022 Directive 50)[12].

Generation adequacy is similar to the resource adequacy reliability criteria determined by the North American Electric Reliability Council (NERC). This criterion needs to be low enough to avoid causing unnecessary waste of idle assets yet high enough to prevent frequent depletion of reserves and power outages. For example, in the winter of 2020/2021, the US PJM energy market retained 48% of the planned capacity reserve according to the most likely load forecast. In the event of possible extreme peak demand, the capacity reserve rate is reduced to 31%; if considering the typical forced outage rate and equipment fault under extreme conditions, the spare rate will drop further to 17%[13].

While there is a clear standard in China's guidelines, practically the empirical value is often negotiated with the system operators.

Note: Although a shortage in fuel supply is a common risk, especially during the Covid-19 pandemic, it is usually not considered in power system adequacy accounting.

2.3 Balancing optimization is a better strategy than capacity expansion

System adequacy evaluates the power system as a whole, instead of focusing on a specific generation type or a specific unit. Similarly, instead of pursuing a specific output of a unit or a type of generation, system adequacy is achieved by designing and optimising mechanisms for scheduling or balancing.

2.3.1 China's sequential decisions making on electricity scheduling

Following the layers in government administration, the electricity schedulers are also categorised into 5 levels: national, regional (cross-province), province level (including direct-administered municipality), city level and county level. Generally, schedulers need to follow the scheduling made by the scheduler one layer up. Generation units and transformer substations also follow the scheduler at their corresponding level.

In practice, a higher level scheduler will determine the allocations for generation output and transmissions across connected-lines. Following this constraint, a lower level scheduler will make

[12] https://www.ndrc.gov.cn/xxgk/zcfb/fzggwl/202204/t20220424_1322795.html

[13] https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_WRA_2020_2021.pdf

finer arrangements within their border of administration. Thus, the decision-making process is known as 'sequential scheduling'.

More importantly, the national and regional scheduler does not actually make a 'schedule' for a specific region, but instead conducts electricity planning.

2.3.2 Improve granularity of electricity power balancing

Scheduling mechanisms that have been based on administration-level governance and sequential decision-making, translates to bureaucratic approvals that fail to respond rapidly and also lack regulation by the free market.

In practice, the cross-province connected-lines are set up to perform scheduled transmission, but do not serve as an infrastructure of grid interconnection.

With these limitations, China can only commit to schedule by week[14], whereas in the pilot electricity trading markets the temporal granularity can be in a day or several hours.

2.3.3 Upscale balancing to reduce demand for capacity expansion

The current sequential scheduling paradigm makes it hard to smooth the peak demand within the regional grid.

Comparatively, modern scheduling agencies in the grid in the US and EU are often the sole entities that are responsible for scheduling electricity generation for the entire region.

For example, there are 7 regional independent system operators (ISO) in the US and 4 transmission system operators (TSO) in Germany. ISOs normally operate across state/province borders[15]. Germany and the US have both decided that a national scheduling agency is unnecessary for the grid to fully function.

Compared to the load characteristics in the US and EU, where the demand is higher in residence and commerce, China has a relatively smaller variation between peaks and troughs[16]. It is possible to upgrade the power system to embrace the balancing mechanism and trading market that operates in a finer temporal resolution to support the rapid change in solar and wind power generation outputs. The best solution is to establish and invest in regional scheduling agencies, and upscale the balancing from intra-province to cross-province, so that the load is smoothed out

[14] https://globalchange.mit.edu/sites/default/files/Davidson_PhD_2018.pdf

[15] https://www.ferc.gov/electric-power-markets

[16] E.g. Load curve, wind and solar output in Northwest China proinvces
https://ieeexplore.ieee.org/abstract/document/8931650

across a larger geographical area as well as a greater number of trading market participants than at present.

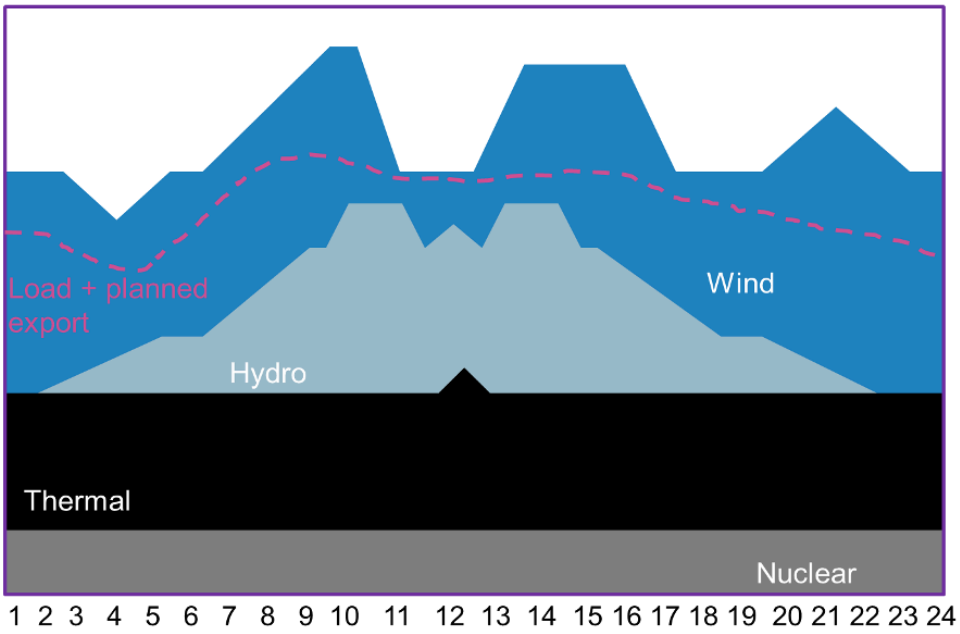

Fig 2-2 Outbound transmission (red curve) usually precedes local balancing arrangements.

Source: Luo Zhiqiang (2017). Power market in SGCC: review and outlook. Presentation at the 9th Clean Energy Ministerial (CEM9), Copenhagen, Denmark

2.3.4 Achieve affordable energy prices and sustainable management through economic dispatch

As sequential scheduling is expected to become infeasible for the frequent electricity trading market, cost-minimising scheduling should be applied, in which the generator with the lowest cost is prioritised[17].

Besides the benefit of minimised cost, this paradigm shift, as stressed by China's NDRC[18] and NEA[19], is also catalysed by the construction of the power trading market by automating the scheduling activity and auditing the numerous trading contracts.

[17] https://www.raponline.org/wp-content/uploads/2017/02/rap-dupuy-li-china-dispatch-reform-ets-2016-december.pdf

[18] https://www.ndrc.gov.cn/xxgk/zcfb/tz/202201/t20220128_1313653.html?code=&state=123

[19] https://news.bjx.com.cn/html/20220221/1205276.shtml

2.4 Energy transition reduces the risk of price volatility

Since the second half of 2021 along with the Covid-19 pandemic recovery , the world's energy prices have experienced skyrocketing rises. This reminds us once again of the importance of system resilience. We should be clear that without the extensive deployment of wind and solar that supplies nearly 12% of the energy mix, the power outage crisis would be more devastating in China. The main reason for power outage is the high price of coal and the restricted supply of resources, which leads to a group of coal power companies reportedly losing revenues and becoming reluctant to retain operation, as well as an increased number of units in shutdown and maintenance[20].

To shift away from fossil-fuel dependency, it is essential to make a full energy transition to renewables.

To support a smooth transition into utilising new energy, an evolution into the novel power system is required. This is also supported by several high-level decision makers in the Chinese government[21, 22].

[20] http://m.stdaily.com/index/yaowen/2021-09/29/content_1223000.shtml

[21] http://www.xinhuanet.com/politics/leaders/2021-03/15/c_1127214324.htm

[22] http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/44687/45175/zy45179/Document/1701277/1701277.htm

3. Assessment of system adequacy in East China during summer

Using case studies of East China (this section) and Central China (section 4), we assess the system adequacy of the regional power grid on the annual scale. We assess the sufficiency of the annual power generation resources in comparison with demand at all times, and also compare challenging periods, such as when energy demand peaks.

The results of this assessment are used to understand the topic due to the scarce availability of grid data.

3.1 East China is a centre of the power demand

East China is the economic centre of China and has a large power load. The East China Power Grid includes the city of Shanghai and four provinces: Jiangsu, Zhejiang, Anhui, and Fujian. East China's population accounts for one-fifth of the country's population and with an annual GDP accounting for about one-quarter of the country's total GDP. The power consumption approximates to 1.8 trillion kWh, or one quarter of the national total figure. The peak load in summer 2020 occurred on August 14 at 312 million kW[23].

Table 3-1 Power Generation Capacity of East China in 2020, by province (MW)

	Shanghai	Jiangsu	Zhejiang	Anhui	Fujian	East China (Total)
Hydro	0	2650	11710	4740	13310	32400
Thermal	24500	100790	63580	55610	34780	279250
Nuclear	0	5490	9110	0	8710	23310
Wind	820	15470	1860	4120	4860	27130
Solar	1370	16840	15170	13700	2020	49090
Total	26690	141240	101410	78160	63690	411190

Source: China Electricity Council Data, summarised by Draworld

[23] https://shoudian.bjx.com.cn/html/20201123/1117332.shtml

East China has always been the receiving end in the grid and the electricity flow. Until 2020, there were 11 cross-regional ultra-high voltage direct current (DC) transmission lines in operation in the East China Power Grid, with an external capacity of nearly 70 million kilowatts. In East China, there is an arrangement of East-bound Power Transmission from Anhui, identifying Anhui as the power transmitter end and Shanghai as the power receiving end.

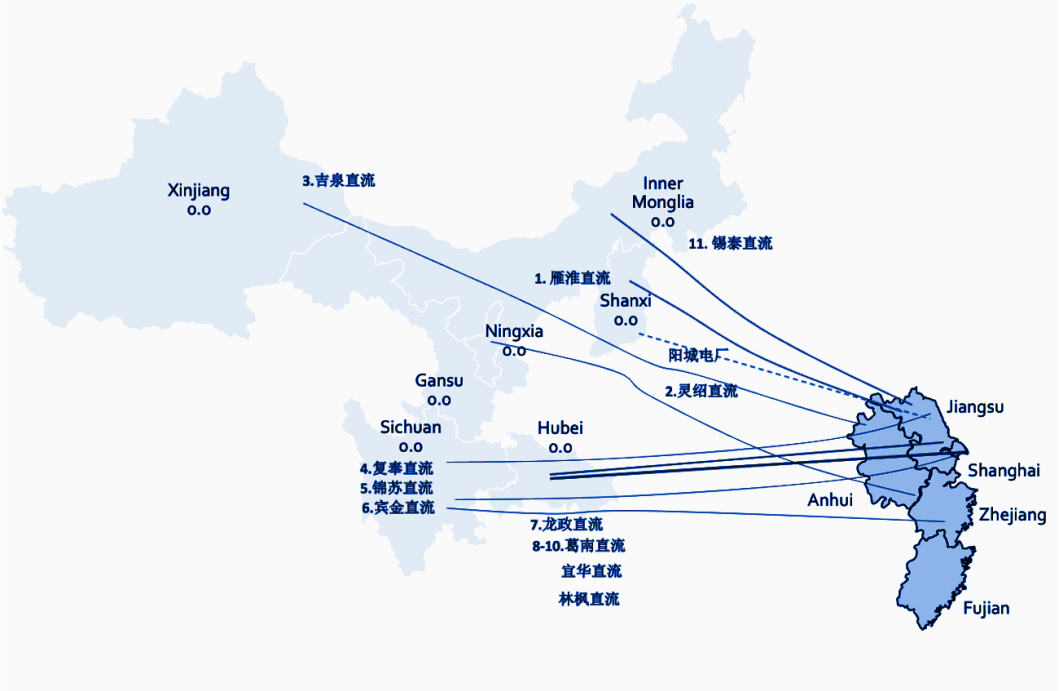

Figure 3-1 East China's cross boundary power transmission as receiving end (until 2020)[24]

Note: Anhui is traditionally the origin of power transmission towards the Yangtze river delta region, especially towards Shanghai. This chart only includes its net receivings.

The largest electric load in East China generally occurs in summer when space cooling power demand increases dramatically. The share of space cooling can reach as much as 50% of peak electricity demand on extremely hot days. This also means that the summer peak is the most difficult moment for the system to balance. Due to the varied load characteristics between regions, the peak time of electricity consumption in summer is slightly different. In East China as a whole, the peak electricity consumption in summer usually occurs between mid-July and late August[25]. Among the regions, Fujian, which is at the southernmost end of East China, the first peak in 2020 was on July 24; while the cities in the Yangtze River Delta region generally peak similarly in

[24] Summarised from openly accessible information, such as: https://www.sohu.com/a/389377057_823256

[25] https://shoudian.bjx.com.cn/html/20201123/1117332.shtml

mid-August; Zhejiang had high temperatures in late summer and the maximum load appeared on August 25.

According to the estimation of the representative load curve in 2018[26], the peak load of the whole region is equivalent to about 92% of the total peak electricity consumption of each province. That is to say: based on the current load characteristics, if the installed capacity is only to meet the maximum load, using the whole region as the balancing area will reduce the capacity demand by approximately 8%, compared to balancing within each province, which is the current reality.

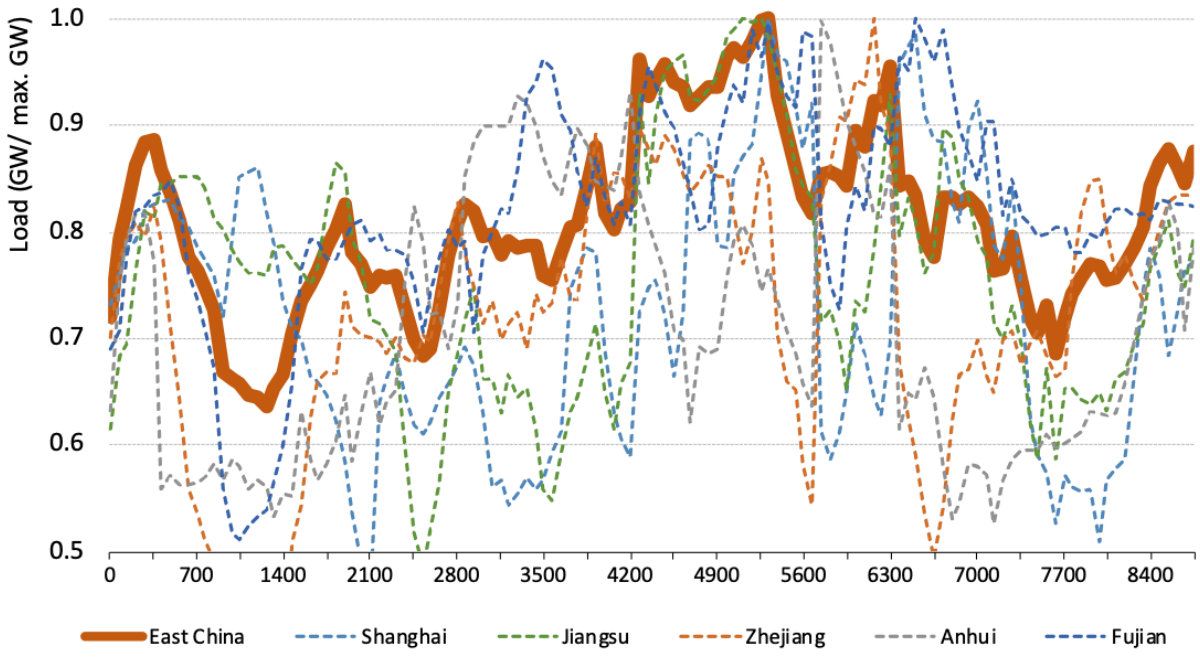

Figure 3-2 Regional peak load is smaller than the sum of peak loads in each area.

Source: 2018 Load curve, published by NDRC, summarised by Draworld

[26] The load balance data of 2020 is not accessible yet. Data of 2019 significantly differs from 2020, and is insufficient for analysis.

3.2 Wind and solar both have evident capacity credits

Volatility is a feature and is not equivalent to uncertainty in power supply. Solar generates electricity when the sun is out, therefore power generation fluctuates with sunrise and sunset and the presence or absence of clouds. A short-term forecast removes most of the uncertainty.

Capacity credit measures the consistent unit output at the peak consumption time of the system, similar to the concept of effective load-carrying capacity (ELCC) in Europe and America[27]. For example, if the load peaks at noon, when sunlight is most abundant, the capacity credit for solar can reach 60% or higher. If the load peaks in the winter evenings, in many regions the wind is also quite strong, leading to a wind output of 50%. Given a certain system, the capacity credit, or load carry capability, can be calculated either from the statistical analysis of the actual full year 8,760-hour operation (365 days*24 hours), or from the simulation analysis using power supply characteristics. Obviously, the statistical result cannot be easily generalised to fully accommodate practical scenarios because it is affected by various system factors besides the output characteristics itself. For example, when there are not many solar installations and the demand peak is still at noon, adding solar will not cause any reduction in its capacity credit. But if the net load (i.e. total load minus solar) peaks in the evening, the capacity credit of newly added solar will decrease and eventually approximate to zero, which means that adding more solar will not meet the peak load demand.

Based on the current power mix and demand characteristics, both wind and solar have significant capacity credit. Based on the 8,760-hour load and Jiangsu's output curve, our evaluation shows that at peak electricity consumption in summer (such as the week of mid- to late August), solar output accounts for 60% of the rated capacity, whereas wind power accounts for 30%.

[27]https://blog.ucsusa.org/mark-specht/elcc-explained-the-critical-renewable-energy-concept-youve-never-heard-of/

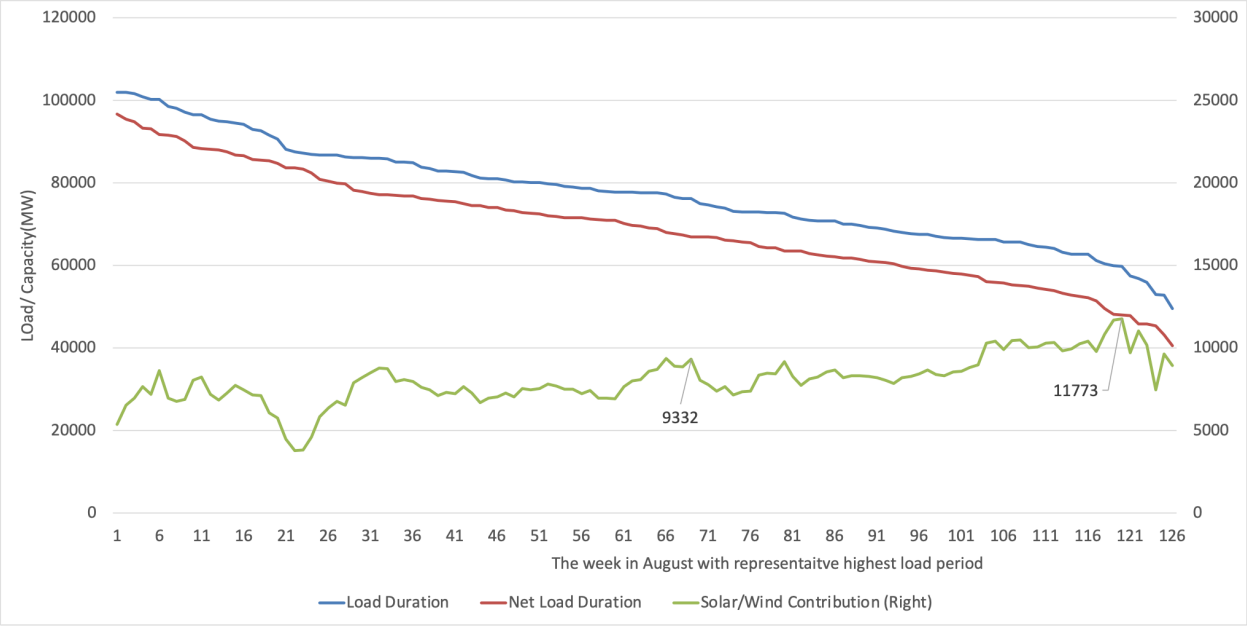

Figure 3-3 Load curve, wind and solar's capacity credits, Jiangsu 2018.

Source: Load curve data from NDRC, Wind and solar data from https://www.renewables.ninja/, compiled by Draworld

3.3 In summer, some provinces in East China have difficulty balancing independently

The normal condition would mean that the external power supply maintains its normal level, and both wind and solar could maintain their normal capacity credit. In such cases, the system adequacy reaches its highest level. As for varying conditions, we would take the following aspects into consideration: local controllable installed capacity; capacity credit output of wind and solar; and capacity supported by external power transmission.

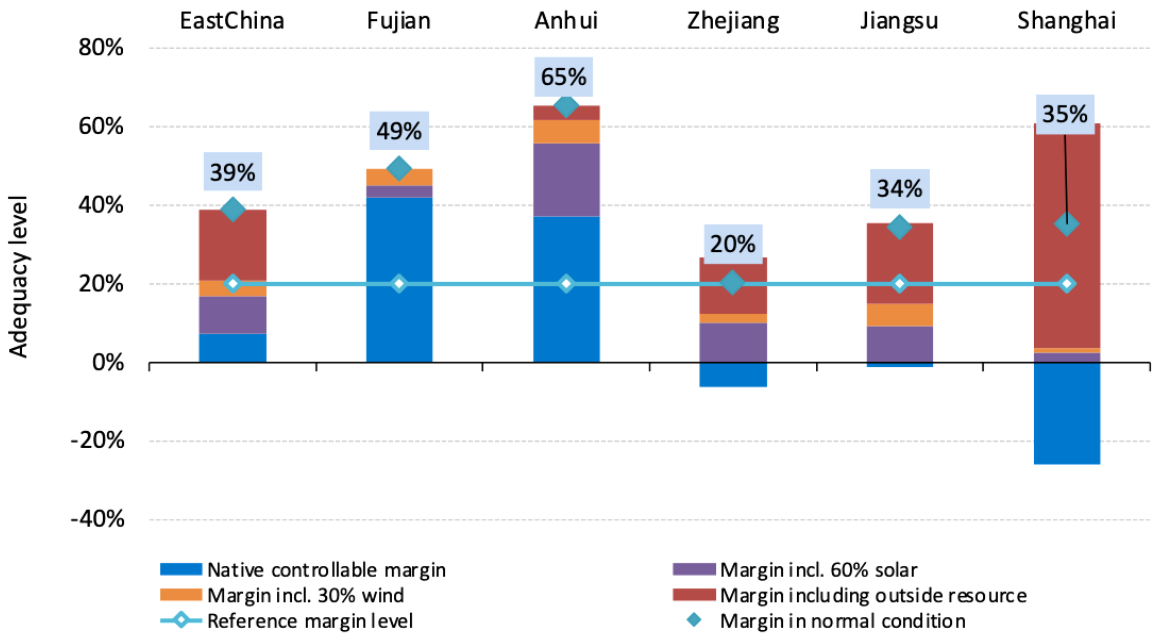

Figure 3-4 System adequacy balanced by each province versus system adequacy within the whole region.

Source: Calculated using power source capacity, transmission and load data, by Draworld

With the support of local installations, external transmission as well as the contribution of solar and wind, each region in East China can ensure a sufficient level of reserve rate. Based on projected maximum demand and available capacity for 2020 to 2021, Figure 3-4 shows each province and the total estimations. In general, according to the overall scheduling arrangement in East China, the system adequacy can be above 30% in 2021, benchmarking to the possible peak load. All provinces here can reach a balance under normal circumstances, although Zhejiang is balanced at a critical point.

In Shanghai and Zhejiang, the local load is less than the maximum demand. From the perspective of local installations, Zhejiang and Shanghai cannot meet the overall demand. If a large proportion of external transmissions are down, and/or the local solar output drops, then the system reserve rate in these two regions is likely to decrease significantly but still be higher than the expected maximum demand of 320-330GW.

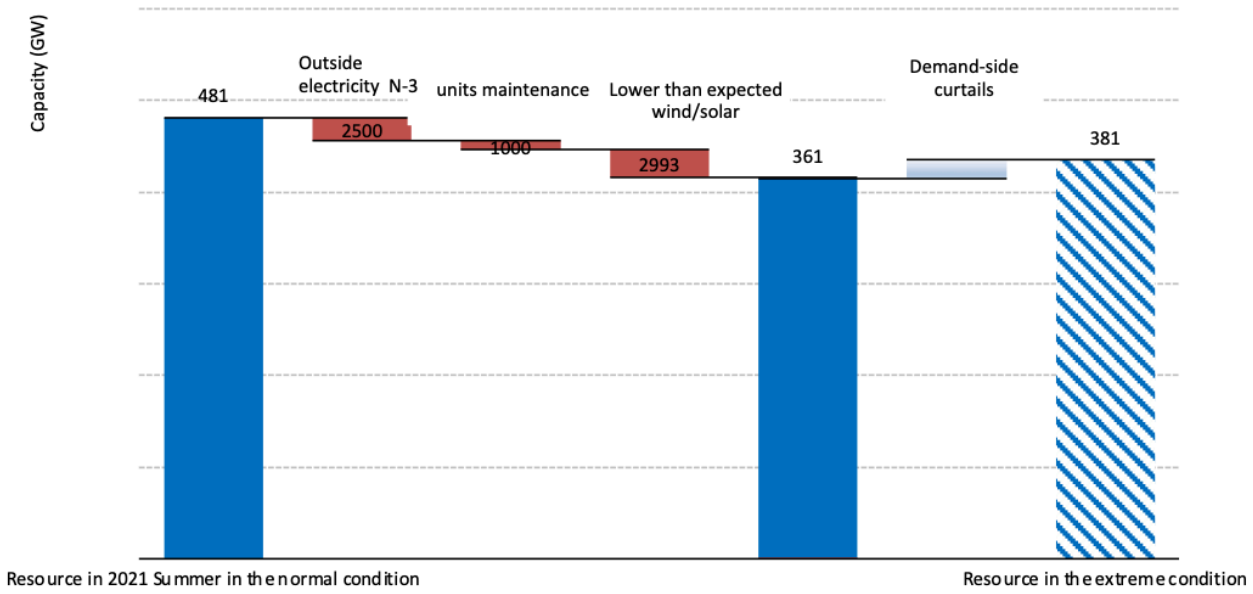

Figure 3-5 System adequacy with its variation under regional balancing, East China.

Balancing over a larger area can reduce redundant installations by 8%. The economic development level and electricity price of each province covered by the East China Power Grid are not the same. The newly established thermal power benchmark price among different provinces only differs within a range of 3 cents/kWh, which shows that the market of each province is also similar. Additionally, the time when electricity load reaches its peak is similar in different provinces. However, due to the large power load in the East China region, reducing redundant installations by 8% is equivalent to a reduction of about 30 million kilowatts of installed capacity. If calculated using the most cost-effective natural gas plant (2,800 Yuan/kW), this is equivalent to a saving of more than 90 billion Yuan in fixed asset investments.

Overall, East China has sufficient generation from the established capacity because the system adequacy is generally higher than 20%. Balancing over a broad region is also a robust response when facing greater uncertainty. From 2020, under the condition of moderate growth in demand and the continuous deployment of new power generation sources in local and external power sources, system adequacy can be ensured without adding any fossil power for the next several years.

4. Assessment of system adequacy in Central China during winter

4.1 Central China provinces have potential for regional load balancing

The Central China Power Grid is located in the central part of China. It includes Hubei, Hunan, Henan, and Jiangxi. The Three Gorges (Hubei) and many other hydropower generation plants are located in this region, and many outbound transmissions originate from the region. Due to the geographical and climatic characteristics of Hunan and Jiangxi, the load in winter is often as high as in summer. Sichuan and Chongqing are both administered by the Central China Power Grid and were originally connected to Central China through 500kV AC connected-lines, but this has been changed to Chongqing-Hubei DC interconnection, so it belongs to an independent regional power grid and is within the scope of this case analysis.

Table 4-1 Installed Capacity in Central China by province, 2020 (MW)

	Hubei	Hunan	Henan	Jiangxi	Central China (Total)
Hydro	37570	15810	4080	6600	64050
Coal	33160	22690	70680	24550	151080
Nuclear	0	0	0	0	0
Wind	5020	6690	15180	5100	32000
Solar	6980	3910	11750	7760	30390
Total	82730	49090	101690	44010	277520

Source: China Electricity Council data summarised by Draworld

Throughout the year, the Central China Power Grid has both received and sent electricity. In recent years, channels were added in Central China to receive transmission from southwest hydropower and northwest power sources. Within the Central China region, Hubei's Three Gorges and Gezhouba continued to send out hydropower, while other provinces maintained a state of net receiving.

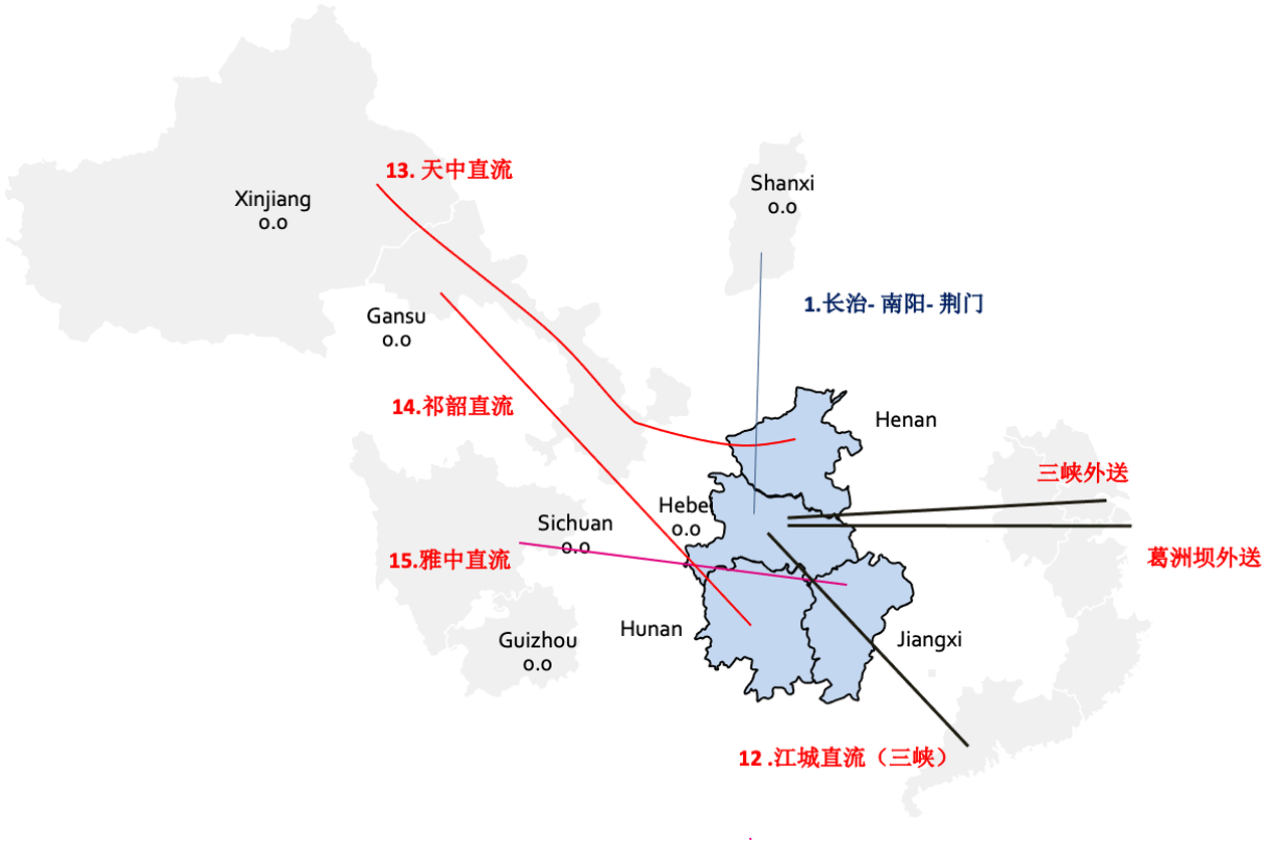

Figure 4-1 Imports and exports of Central China cross-boundary transmission (until 2020).

Source: data compiled from https://www.sohu.com/a/389377057_823256 etc, by Draworld

Electricity consumption peaks at different times due to the variation in load characteristics in different areas. In summer, the electricity consumption in the Central China region usually peaks between July and early August. However, the peak in Hunan and Jiangxi may appear in winter. Cities in Central China are more mutually complementary. This also indicates that a regional cross-province balancing operation will have greater benefits in Central China than in East China.

According to estimations based on the 2018 load curve[28], the peak load of the entire region is equivalent to about 89% of the combined peak electricity consumption of each province. Based on the current load characteristics, if the installed capacity is only to meet the maximum load, balancing as the whole region would mean a decrease of 11% in capacity demand, compared to balancing within each province, which is how the system currently operates.

This also means that a cross-province balancing operation makes the entire load curve smooth in winter and summer, which can effectively improve the utilisation rate of various units and reduce the unit cost of generated electricity.

4.2 The power generation resources in Central China provinces are largely sufficient in the winter

In this section, we evaluate the contribution of power in Central China based on various resources, including the local installations, the capacity credit of wind and solar, and the electricity transmitted from external sources.

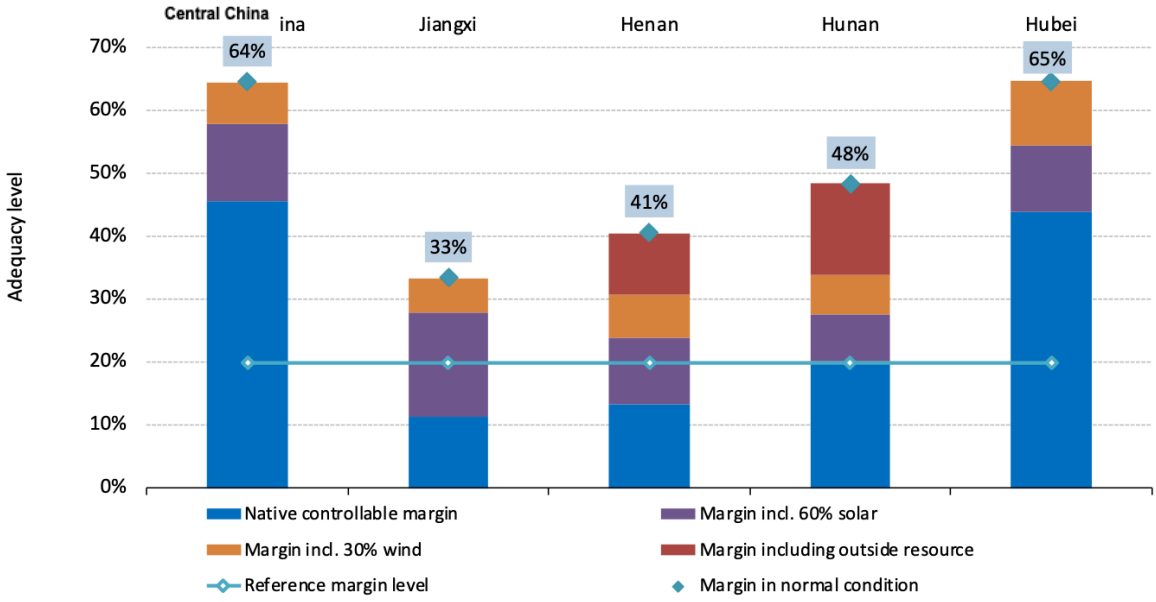

Figure 4-2 System adequacy under different conditions, balanced by provinces and in total.

Source: calculated based on collected generation capacity, transmission (>500kV) and load information, by Draworld

[28] Load curve for 2020 is not yet available. According to the weather condition, the load curve in 2019 appears to be less representative, and differs against 2020 greatly.

Under normal circumstances, Central China has a greater magnitude of overcapacity than other parts of China (more than 30%[29]). This is mainly due to the abundance of locally installed capacity, even though a considerable part of Hubei's installed capacity is for outbound transmission.

Yet in finer-scoped observations, Hunan and Jiangxi have insufficient local controllable installed capacity. If there is an event more severe than an N-2 downtime from external sources, and also with a reduced local solar output, then these two regions are likely to deplete the local system reserve. If wind power can provide capacity to support Hunan and Jiangxi, then the risk of supply depletion can be mitigated.

The grid management should not rely on baseload coal power to solve the problem of system adequacy. Any solution must go through checks of efficiency and cost-effectiveness to ensure that such solution is rational. The duration of the extra load is short term, therefore coal-fired power plants are unsuitable because they need to run for more than 4,000 hours to be economically beneficial.

4.3 Regional cross-province balancing saves 11% of installed capacity

In Central China, due to the mutually complementary load characteristics, a large balancing range will play a greater role than in East China, saving 11% of redundant installed capacity and eliminating the demand for additional installations. Estimating the cost of natural gas single-cycle units, regional cross-province balancing is equivalent to saving more than 45 billion Yuan in redundant installation investment.

Besides the fore-mentioned cross-regional 500kV transmission, the local units have historically been delegated to serve other regions. For example, the Liyujiang Power Plant[30] is the southernmost power support in the Central China Power Grid. It was built in the mid-1950s and has undergone four phases of expansion. In the past, after the expansion and commissioning of the Liyujiang Power Plant, the bulk of electricity was sent to Guangdong. The power plant officially returned to the Hunan power grid in early 2022 and has started to contribute to the local system adequacy.

[29] A reasonable system reserve rate is usually 13%-15%, varied in different provinces, according to http://www.nea.gov.cn/2020-02/26/c_138820419.htm

[30] http://hn.people.com.cn/n2/2022/0116/c336521-35097688.html

Conclusion and suggestions

5.1 Regional cross-province balancing systems are beneficial

Balancing the demand and supply of the power system within a large geographical range and a short time interval, and integrating a variety of output and demand sources, will more efficiently utilise the complementary feature of the power grid and effectively reduce the demand for new installations and reserves.

In East China, the grid system already has adequate resources, which ensures that the system is sufficient without the need for any further addition of fossil power generation in the near future. Balancing in a large range could potentially reduce the redundant installed capacity by 8%. Due to the huge load in the region, the balancing arrangement is equivalent to a reduction of approximately 30 million kilowatts of installed capacity, or a saving of more than 90 billion Yuan.

In Central China, balancing in a large range creates a benefit of saving 11% of redundant capacity, and eliminates the need to have any local power generation additions in the future. Even with the lowest investment cost of installing a natural gas single-cycle unit (2,800 Yuan/kW), this change in balancing scope effectively translates to a saving of more than 45 billion Yuan in redundant installation investment.

To achieve a balancing scheme, several support systems need to be in place, such as investing in the addition of more tie-lines[31], necessary dispatch and balance automation technology, a regulatory governance system, and an appropriate pricing system.

5.2 Building new coal power plants will be uneconomical

The energy sector needs to be fully decarbonised by 2050 so that China can achieve carbon neutrality by 2060. Changes need to be gradually introduced over several years, with comprehensive consideration including acceptable cost (efficiency) while meeting energy balance, security and fairness. A policy framework that covers a broad range of economic, fiscal, industrial, employment, innovation and social policies will enable China to robustly embrace the energy transition and eventually reach carbon neutrality.

Low-intensity carbon emissions are necessary for China's energy system in the future. Coal and coal-fired power are emissions-intensive and uneconomical and should either be phased out first, or have carbon capture and storage (CCS) devices installed. However, after 20 years of research,

[31] The investment is considered to be a small amount due to the short length of such connected-lines.

development and demonstration, the application of CCS technology still has not been fully proved to be feasible for large-scale applications.

The power sector needs to set milestones to reduce carbon intensity. Studies using historical energy and climate scenarios suggest that the power sector has options to implement emissions reduction technologies. The cost of emissions reduction has also been effectively reduced, therefore the power sector industries should lead the process of achieving deep decarbonization and eventually (near) zero emissions. In China's current electricity generation mix, the emission intensity of coal power is 900 gCO2/kWh, while the overall power emissions intensity is 550 gCO2/kWh. The government needs to develop a roadmap for a gradual decline from this level to near zero by 2050, with the accompanying policy tools to achieve such a path.

In the future, China's energy mix will require a large proportion of renewable energy plus large-capacity, low-utilisation natural gas single-cycle power generation, as well as power sources that meet seasonal adjustment needs. Due to the volatility of wind and solar, its final assembly will be many times higher than the maximum load to achieve a high proportion of power generation. To make up for the power supply under extreme conditions such as zero output from wind and solar, technologies with low investment costs, such as demand-side response and natural gas single-cycle units, should be preferred over coal power, which only is economically feasible with high annual operating hours.

Increasing the proportion of renewable power in the mix would have strong implications for energy technology and generation infrastructures. For example, nuclear power is only promising if it is sufficiently miniaturised and modularized, such as by using a high-temperature gas-cooled reactor (HTGR). In the long run, natural gas can also be easily accessible from methanation after electrolysis of water to in the hydrogen production workflow, which may solve the problem of emissions after the complete phasing out of coal power.

5.3 Short-term policy recommendations for establishing a new power system

- **Monitor and evaluate system adequacy annually and improve information transparency.** Similar to the practices of the European Union for the Co-ordination of Transmission of Electricity (UCTE)[32] and the North American Electric Reliability Corporation (NERC)[33], it is recommended that the corresponding Chinese government regulatory authorities (e.g. Market Supervision Department of the National Energy Administration) carry out supervision on the issue of system adequacy transparency, and require scheduling

[32] https://www.ucte.org/_library/systemadequacy/saf/UCTE_System_Adequacy_Methodology.pdf; https://www.entsoe.eu/outlooks/midterm

[33] https://www.nerc.com/pa/RAPA/ra/Pages/default.aspx

agencies to prepare and publish system adequacy review reports and outlook annually. At present, the latest Measures for the Administration of Electric Reliability (for Interim Implementation) issued in 2022 has required retrospective reports (Article 50), but clarification needs to be made for Article 51 i.e. release power reliability metrics on a regular basis.

- **Increase investment in the construction of power grids below 500kV so that the infrastructure can support a regional cross-province power balancing scheme and a unified electricity trading market.** Investment is especially important in Central China, where the existing infrastructure is relatively weak. At the same time, the trading market should be designed to provide a unified arrangement regarding the production and consumption of electricity rather than allowing for privileged power supplies (e.g. the inter-provincial market) to separate the market and ignore the supply and demand dynamics of power generation and demands in the respective regions. To better understand the problem and the solution, a higher level of social perception on how the system could and should work remains essential.

Appendix: Methodology and data sources

1. System Reserve Rate

According to the technical code of design for the electric power system (DL/T 5429-2009), the System Reserve Rate is defined as:

$$K = \frac{N_y - P_m}{P_m}$$

where:

K ——System Reserve Rate

N_y ——Capacity contributed by the system (kW), usually calculated by the capacity contributed at the peak time of the demand.

P_m ——Peak load of the system (kW), often projected.

2. 8,760-hour Load Curve for each province

Load curves at the province level were published by NDRC to support the establishment of the electricity trading market.

The load curve of 2018 has a relatively high granularity and is provided at per-day or even per-hour levels. Resolution decreased for the load curve of 2019.

The impact of Covid-19 in 2019 is treated as an abnormal data point and therefore this report conducts estimation and calculation with the 2018 load profile.

3. Installed capacity in the power sector, 2020

This data is compiled using the installation data of each power source's Chinese Electricity Council Annual Statistical Report 2021 (《2021年全国电力工业统计快报一览表》), combined with the installation sum by the end of 2020 as well as the current power mix.

4. Cross-province interconnection lines above 500kV

No.	Region	Province of Origin	Name	Alternative name	Voltage	Designed Capacity	Origin	Destination	Commission Date	Remarks	AC/DC
1	East China	Shanxi	雁淮直流	晋北-南京	±800	800	山西雁门关	江苏淮安	2017/06		DC
2	East China	Ningxia	灵绍直流	灵州-绍兴	±800	800	宁夏灵州	浙江绍兴	2017/06		DC
3	East China	Xinjiang	吉泉直流	准东- 华东	±1100	1200	新疆昌吉	安徽古泉	2019/09		DC
4	East China	Sichuan	复奉直流		±800	640	四川宜宾	上海奉贤	2010/07	向家坝水电站	DC
5	East China	Sichuan	锦苏直流		±800	720	四川裕隆	江苏同里	2012/12	锦屏水电站	DC
6	East China	Sichuan	宾金直流		±800	800	四川双龙	浙江浙西	2014/07	溪洛渡水电站	DC
7	East China	Hubei	龙政直流		±500	300	湖北龙泉	江苏政平	2002/12	三峡外送	DC
8	East China	Hubei	葛南直流		±500	120	湖北葛洲坝	上海南桥	2089/09	葛洲坝水电外送	DC
9	East China	Hubei	宜华直流		±500	300	湖北宜昌	上海华新	2006/11	三峡外送	DC
10	East China	Hubei	林枫直流		±500	300	湖北团林	上海枫泾	2011/03	三峡外送	DC
11	East China	Inner Mongolia	锡泰直流		±800	1000	内蒙古锡盟	江苏泰州	2017/10		DC
12	Southern	Hubei	江城直流		±500	300	湖北江陵	广东鹅城	2003/10	三峡外送	DC
13	Central China	Xinjiang	天中直流	哈郑直流	±800	800	新疆哈密	河南中州	2014/01		DC
14	Central China	Gansu	祁韶直流	酒泉-湖南	±800	800	甘肃祁连	湖南韶山	2017/06		DC
15	Central China	Sichuan	雅中直流		±800	800	四川雅安	江西抚州	2021		DC
Total						9680					
1	Central China	North China	长治- 南阳-荆门		1000	500	山西长治	湖北荆门	2012/11		AC
2	Central China	North China	辛洹线		500		河北辛安	河南洹安	2003/11	冷备用	AC
3	East China	Shanxi	阳城电厂		500		山西阳城	江苏淮阴		三回500kV	AC

Source: compiled by Draworld using public accessible data (https://www.sohu.com/a/389377057_823256 etc)