Energy Transitions Commission

CHINA ZERO-CARBON ELECTRICITY GROWTH IN THE 2020S:

A Vital Step Toward Carbon Neutrality

Executive Summary

BY ROCKY MOUNTAIN INSTITUTE, ENERGY TRANSITIONS COMMISSION

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SUGGESTED CITATION

Yiyan Cao, Ji Chen, Bingqi Liu, Adair Turner, and Caroline Zhu, *China Zero-Carbon Electricity Growth in the 2020s: A Vital Step Toward Carbon Neutrality,* Energy Transitions Commission and Rocky Mountain Institute, 2021, **http://www.rmi.org/url here**.

All images from iStock unless otherwise noted.

ACKNOWLEDGMENTS

The authors thank the following individuals who contributed time and expertise to this research through interviews and support:

Clyde Loutan, California ISO
Louise Clark, UK National Grid
Mark Dyson, Rocky Mountain Institute
Rui Wang, China Electric Power Planning & Engineering Institute
Ning Zhang, State Grid Energy Research Institute
Xue Han, Center for Renewable Energy Development

The team wants to thank the ETC Commissioners and the ETC network for their active contribution.

Special thanks to the Angela Wright Bennett Foundation, Bloomberg Philanthropies, ClimateWorks Foundation, Quadrature Climate Foundation, Sequoia Climate Fund, and The William and Flora Hewlett Foundation for their support of this report.

** Organizations listed alphabetically.*

ABOUT US

ABOUT ENERGY TRANSITIONS COMMISSION

The Energy Transitions Commission (ETC) is a coalition of global leaders from across the energy landscape: energy producers, energy-intensive industries, equipment providers, finance players, and environmental NGOs. Our mission is to work out how to build a global economy that can both enable developing countries to attain developed world standards of living and ensure that the world limits global warming to well below 2°C and as close as possible to 1.5°C. For this objective to be reached, the world needs to achieve net-zero greenhouse gas emissions by around mid-century.

ABOUT ROCKY MOUNTAIN INSTITUTE

Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing.

EXECUTIVE SUMMARY

On September 22, 2020, President Xi Jinping announced that China aims to achieve carbon neutrality before 2060 and peak emissions before 2030.[1] This was an extremely important step forward in the international fight against climate change and reflects China's determination to provide responsible global leadership.

The key to achieving this target is to electrify as much of the economy as possible and to ensure that almost all electricity is generated from zero-carbon resources well before 2060. The appropriate strategy compatible with China's long-term carbon neutrality target should therefore be to ensure that all growth in China's electricity generating capacity is zero-carbon, including no new coal investment.

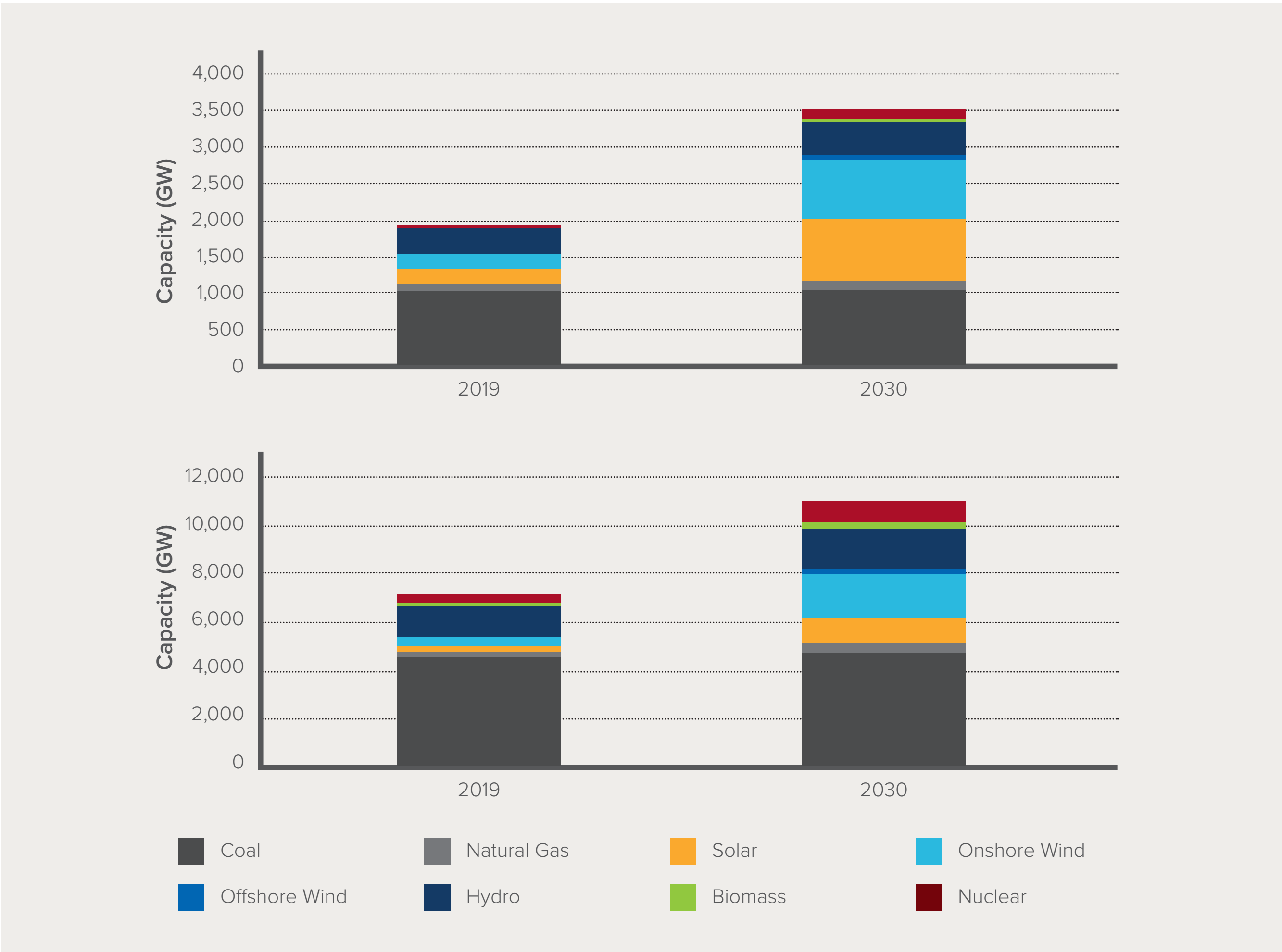
Any new coal investment threatens to create assets that will either make the carbon neutrality target unattainable or that will have to be closed down well before the end of their useful life. This would create a waste of investment resources and make it more difficult to decarbonise the power system.

In this report we therefore assess a scenario for 2030 aligned with what is needed to fully decarbonise China's power sector by 2050, which we will refer to as the Zero-Carbon Investment Scenario. This scenario, shown in Exhibit 1, includes the following assumptions:

- Electricity supply reaches 11,000 TWh by 2030, an increase of 54% above current levels, reflecting an average growth rate of 4% per year.
- No new coal supply is added beyond the 1,041 GW in place in 2019, but with a slight increase in coal generation as existing assets are used more intensely.
- Variable renewables capacity increases from 408 GW in 2019 to 1,650 GW in 2030—which equates to about 110 GW annually—with variable renewable generation accounting for 28% of total generation in that year.
- Total non-fossil fuel generation reaches 53% of the total, slightly above the target of 50% proposed by China's government in 2016.

EXHIBIT 1

Generation and Capacity Mix in 2030 under the Zero-Carbon Investment Scenario



This scenario would need to be followed by further rapid zero-carbon supply expansion from 2030 to 2050 and by the gradual elimination of existing coal generation—unless fitted with carbon capture and storage—during that timeframe. Achieving this scenario will help make the "peaking before 2030" objective attainable and put China on a path compatible with its 2060 objective.

This report therefore describes:

- The economic case for zero-carbon power and the path to low-cost green electricity;
- The technical feasibility of rapidly expanding variable renewable energy (VRE) generation;
- Approaches to balancing supply and demand in a system with an increasing share of VRE; and
- The policies required to deliver zero-carbon electricity growth through 2030 and beyond.

ZERO-CARBON POWER IS ECONOMICALLY VIABLE IN CHINA

Across the world, the cost of renewable electricity generation has fallen dramatically over the past 10 years. Estimates of the global average levelized cost of electricity for solar are down 85%, onshore wind is down 60%, and offshore wind costs have now started a rapid fall, down over 60% in just five years.[2] Renewable electricity generating costs are increasingly falling below those of fossil fuels in China and most geographies around the world.[3]

In China, solar costs are already falling below the cost of new coal generation, and onshore wind will soon follow. Offshore wind costs will likely become competitive during the 2020s. Zero-carbon generation sources, such as hydro and nuclear, are fully competitive with coal as providers of baseload electricity and it is commonly acknowledged that hydro is the cheapest generation source in China. New zero-carbon generation sources are thus already broadly competitive with new coal power plants.

In addition, by the late 2020s, new wind and solar developments will deliver electricity below the cost of many existing thermal plants, making many existing coal plants uneconomic. This stranding risk is increased by the current overcapacity of China's coal fleet, which has a national average capacity factor around 50%.

Renewable costs will continue to fall but the pace of decline will be influenced by Chinese policies. Historically, the initial subsidy regime and quantitative targets have driven impressive development of zero-carbon electricity, industry expansion, and cost reductions. Certainty about the quantitative pace of expansion has enabled the industry to achieve the economy of scale and learning curve effects that have brought costs down to competitive levels. However, the recent change of subsidy regime has produced a slowdown in the pace of wind development and there is a danger that the pace of investment may be too slow in the coming years. This could lead to new coal investments filling the gap, creating unnecessary cost and stranded assets later on.

It is therefore vital to maintain a supportive policy regime to drive rapid growth and unlock further cost reductions. Such a regime must create certainty for investors by setting targets for the percentage of power derived from renewables and/or specific quantitative targets for wind and solar capacity expansion.

Provided such policies are in place, renewable generation costs will continue to decline, delivering new supply at costs below both new coal and many existing coal plants before 2030.

TECHNICAL GRID MANAGEMENT CHALLENGES ARE SOLVABLE

While the economics favour the rapid expansion of variable renewable energy (VRE), some grid operators are concerned about the potential technical challenges that a growing VRE share will create. These include frequency control, voltage control, fault ride through, and capacity utilisation for high-voltage direct current (HVDC) transmission lines. But many other countries are now running systems in which VRE shares reach far above 50% (and indeed close to 100%) during specific hours. This reflects the fact that there are technical solutions to all of the challenges mentioned.

EXHIBIT 2

Potential Technical Challenges and Solutions

Types	Challenges	Solutions
Frequency control	VRE is not dispatchable at will, and its future output cannot be predicted precisely. If supply and demand are in significant imbalance, frequency deviations can cause generating units to trip off.	• Improve forecasting of renewable output. • Predict and reduce extreme short-term renewable ramping. • Use VRE and other nonthermal plants to provide frequency control services. • Improve system inertia monitoring and deliver it in new ways.
Voltage control	Reactive power must be compensated instantaneously and locally to maintain the power factor within the permitted range.	Deploy static var compensators, static var generators, static synchronous compensators, or thyristor-controlled series capacitors.
	Harmonic waves are inevitable and would affect the voltage stability.	Filters should be used to deal with the harmonic waves in voltage and improve power quality.
Fault ride through	Generation units need to be able to ride through the voltage turbulence before the system returns to normal.	Retrofit existing plants to meet high voltage ride through standards and impose those standards on all future VRE plants.
Capacity utilisation of long-distance HVDC lines	VRE export over HVDC lines creates variable and sometimes low-capacity utilisation, with apparent need for thermal power to “fill the line.”	There is no technical need for an HVDC line to run at a steady rate, and the technical minimum utilization of the dominant form of HVDC currently deployed in China is 10% of nameplate capacity.
	Commutation failure arises when disturbances produce an increase in DC currents and temporary interruption of power transmission.	The same set of tools that can manage frequency and voltage variation in a high VRE system (e.g., synchronous condensers, battery storage, non-thermal sources of inertia, reactive power compensators, etc.) can also offset the impact from commutation failure. Also, a new generation of voltage sourced converter HVDC is able to deliver excellent voltage control capacity, eliminating the commutation risk, and simplifying technical requirements for both sending and receiving provinces.

In summary, provided China implements the required policies and optimizes grid operation by allowing the deployment of innovative solutions, no technical grid management issues will prevent the growth of VRE to shares far above current levels.

BALANCING SUPPLY AND DEMAND BY HOUR, DAY, AND SEASON ARE MANAGEABLE WITH HIGH-VRE PENETRATION

The variable nature of wind and solar can create more challenges in balancing supply and demand than in a system where the vast majority of power supply is dispatchable thermal or hydro power. But several countries and regions across the world have already reached VRE shares higher than the 28% target in our Zero-Carbon Investment Scenario for China in 2030. Many countries plan to increase the share of zero-carbon electricity to at least 50% and in some cases more than 70% by 2030.

International experience shows that for renewable penetrations up to the levels typically seen in other advanced countries today (e.g., 20%–30%), flexibility challenges can in almost all cases be solved via flexible use of existing thermal capacity, whether gas or coal. For example, in a typical week in August, hard coal generation in Germany varied from 1.4 to 6.5 GW (a 79% variation) to support the system balance.[4] As shares grow to much higher levels in the system, a wider range of options will be needed, such as pumped hydro, battery storage, and demand-side resources.

Implementing these flexibility options will in some cases involve additional costs. However, this additional cost is offset by the lower cost of zero-carbon generation and decreasing cost of innovative flexibility solutions, making total system cost flat or even lower. An estimate from the Energy Transitions Commission shows that it will be possible by the mid-2030s to build systems that rely on VRE for as much as 85% of all electricity supply. And furthermore, this can be done with total system costs that are as low (and in some cases lower) than fossil fuel-based systems today.[5]

Within the global picture described above, the challenge faced by any specific country reflects its supply and demand characteristics. In China's case, there is nothing about the pattern of demand that creates any distinctive challenge. However, two features of China's electricity supply—its starting point of reliance on coal rather than gas, and the less flexible nature of its hydro resource—create distinctive but manageable problems. In addition, China's balancing problem is made more difficult by inflexibilities in interprovincial trading arrangements.

If the Chinese power system could operate as one integrated national system, with complete interconnection between provinces, existing thermal flexibility could easily support a 28% share of VRE in 2030. This level could be achieved even if hydro resources (as well as nuclear) were completely inflexible on an hour-by-hour basis. Exhibit 3 shows the shape of China's possible summer and winter demand and non-thermal supply in 2030 under the Zero-Carbon Investment Scenario. With pumped storage hydro (PSH) shifting a small share of overnight demand to the daytime, and gas generation providing some evening and night-time supply, the required variation in coal power supply is clearly manageable even within the existing level of coal plant flexibility.

In addition to the predictable variations in average hour-by-hour demand and supply shown in Exhibit 3, the system will have to respond to random short-term variations in wind and solar supply (even when averaged across the whole of China's landmass). However, hydro supply could vary significantly on an hour-by-hour basis, even if there are limits to significant variation over a longer time period.

Viewed from the point of view of a theoretical "one China" system, the challenge of balancing supply and demand in the face of a 28% VRE share can therefore be easily managed without major improvements in coal or hydro flexibility.

In today's reality, however, the decentralised nature of China's grid management system introduces additional complications. Existing forms of regional coordination

EXHIBIT 3

Simulated National Daily Balance in Typical Winter and Summer Days in 2030[i]

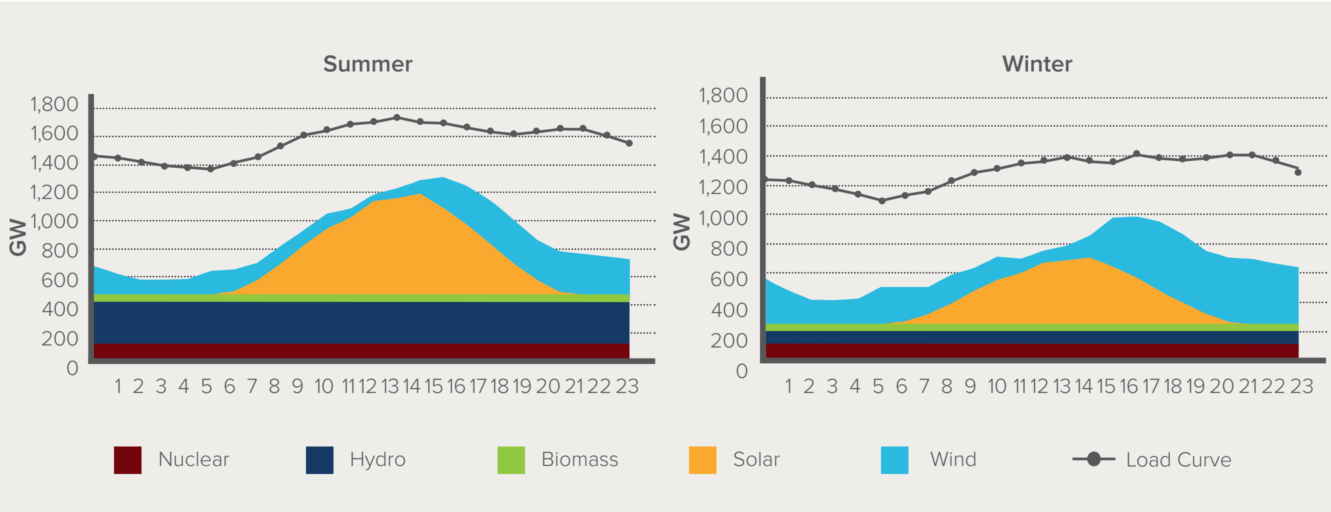
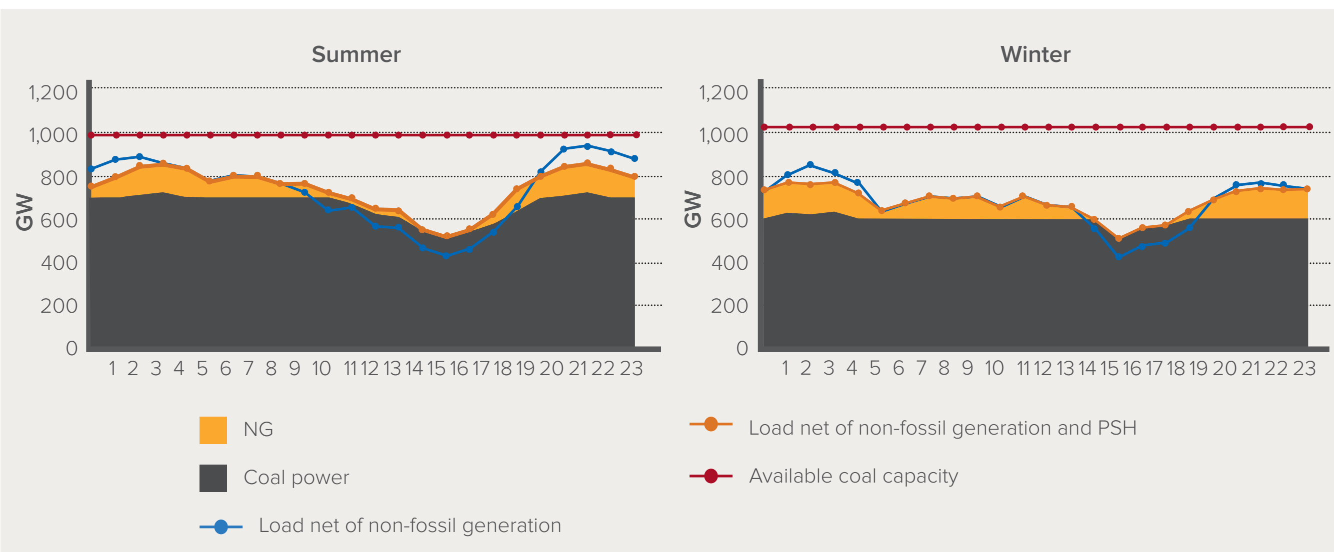


EXHIBIT 4

Estimated Flexibility of China's Coal Fleets, 2030[ii]



[i] Exhibit 3 sets out reasonable estimates of typical summer and winter day national demand profiles in 2030, together with a profile of wind and solar energy production compatible with the capacity estimated for 2030 and with typical daily resource variation. Nuclear, hydro, and biomass are shown with the unrealistically conservative assumption that they will be completely inflexible on an hour-by-hour basis. The implied need for thermal power is given by the space between the zero-carbon supply curve and the total load curve.

[ii] Exhibit 4 demonstrates how the need for thermal power shown in Exhibit 3 could be flattened by pumped storage hydro and met by existing thermal plants.

make possible some short-term adjustment of power excess or shortage between provinces within the same region. However, daily dispatch decisions are primarily made at the provincial level, and nationally coordinated interprovincial export/import contracts are set on an annual basis and treated as fixed on a day-by-day basis. This decentralised approach increases the danger that flexibility resources will be insufficient to deal with a 28% VRE share in 2030.

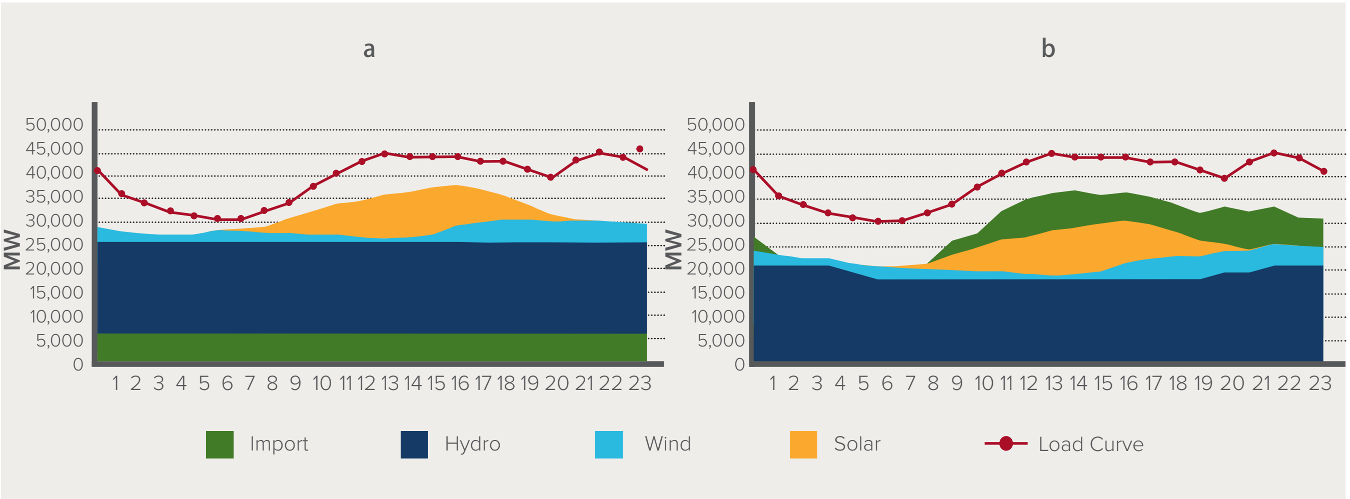
- In the case of an importing province (as Exhibit 5a illustrates) the growth of solar demand usefully reduces the need for peak thermal capacity in the middle of the day, but inflexible imports and hydro supply at night would require more variation in thermal supply than possible with current coal plants. Meanwhile, in spring and autumn, total inflexibility of imports and hydro would require that thermal plants close down entirely for some periods of the day.
- In the case of an exporting province, an inflexible export contract might make it impossible to export all midday solar output (resulting in wasteful curtailment). And high evening wind supply could necessitate total thermal shutdown, which is uneconomic on a daily cycle basis as opposed to a longer seasonal cycle.

While the assumptions used in Exhibit 5 are illustrative and unrealistically simple, they define the fundamental problem. The higher the VRE share, the greater the danger that inflexible import/export contracts and inflexible hydro resources will impose an impossible or prohibitively expensive demand on coal flexibility. To manage an increasing VRE share, China should therefore improve flexibility along three key dimensions while developing the other forms of flexibility resources that will be needed over the long term.

Greater flexibility in interprovincial transactions and in coal and hydro plant operation would provide more than adequate flexibility in the period:

EXHIBIT 5

Demonstrated Daily Balance in an Energy-Importing Province with and without Flexibility Adjustments for Energy Imports



More flexible interprovincial transactions

As discussed in the technical session, there is no technical necessity to run HVDC lines at high and constant utilization rates. More flexible interprovincial energy contracts could create a better match between renewable supply curves in exporting provinces and demand curves in importing ones. For instance, if the interprovincial imports by the importing province illustrated in Exhibit 5a varied in line with that province's demand schedule (Exhibit 5b), this would simultaneously reduce both the required variation in the importing province's thermal output, and solar curtailment in the exporting province.

Increased coal plant flexibility

Coal plant flexibility in power systems is influenced both by physical capabilities and by the market mechanisms in place and the incentives those mechanisms create. Policy should secure increased flexibility along both dimensions.

The 13th Five-Year Plan set targets to conduct coal plant flexibility retrofits that would deliver an additional flexibility resource of around 20% of total nameplate capacity (e.g., about 44 GW increased flexibility in plants with 220 GW total capacity). However only 58 GW of this 220 GW target has so far been achieved.[6] Meeting the 13th Five-Year Plan objective and extending flexibility to as much of the coal fleet as possible should be a high priority.

At the same time, as power systems transition to high VRE and other zero-carbon generation shares, thermal generation shares should and will decline, but thermal plants are likely to play roles as flexible back up for the next 20 years, alongside other competing flexibility sources. Power markets will therefore need to provide high-priced remuneration for peak energy supply to remunerate thermal plants for the flexible services they provide.

Increased hydro supply flexibility

For hydro as for coal, there are two key issues: the inherent physical flexibility of China's hydro resources, and the impact of contracts and incentives on the flexibility with which hydro power is used. Improving the former may require significant investments, but the latter could be rapidly improved via power market reforms.

Analysis conducted by the China National Renewable Energy Center (CNREC) in 2018 suggests that there is major opportunity for market and contract reforms to make hydro a far more flexible resource for daily supply/demand balancing.[7] While in 2020 hydropower can vary in a range between 100 and 200 GW on a daily cycle, CNREC believes that it could vary as widely as 60 GW to over 300 GW by 2035, with a slight further increase in flexibility by 2050.

New forms of flexibility will become more important as VRE penetration continues to grow rapidly between 2030 and 2050. Three technologies—**batteries, demand response,** and **hydrogen**—will be particularly vital and China is excellently placed to be a global leader in each of them. To ensure these technologies reach full maturity will require the right policies to be put in place today, including in the 14th Five-Year Plan. They are not only vital to long-term system balance, but also may provide lower cost flexibility resources even in the short term.

In China, as elsewhere, some forms of increased flexibility will add to total system cost, particularly in the short term. However, just like solar and wind, technologies such as batteries and hydrogen will mature over time, driving down costs. Meanwhile, the costs of renewable and other zero-carbon power generation will be significantly below those of thermal power production. As a result, China's total system costs for a low/zero-carbon system will likely be below those for today's fossil fuel-based system.

APPROPRIATE POLICIES ARE CRITICAL TO ACHIEVE THE 2030 OBJECTIVE

There is no doubt that it is technically and economically possible for China to meet all future growth in electricity supply from zero-carbon sources, building no new coal plants from now on. It is therefore essential that policies—and in particular the details of the 14th Five-Year Plan—are aligned to achieve the objective of zero-carbon growth.

The most important priority is to establish clear quantitative targets for renewable electricity development (supported by targets also for nuclear and hydro supply). This will enable the Chinese wind and solar development and supply industries to achieve the economies of scale and learning curve effects which make maximum cost reduction possible. Therefore, the following measures should be taken:

- A guiding principle of "all new electricity growth from zero-carbon sources" should be established and translated into an indicative penetration target for zero-carbon generation, such as the 53% shown in Exhibit 1.

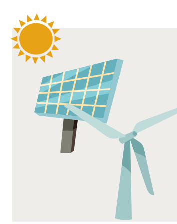
EXHIBIT 6

Policy Recommendations to Achieve Zero-Carbon Power Growth

Quantitative targets for 2030 and the 14th FYP

No new coal investments beyond those coal plants already under construction

Nuclear and hydro growing in line with existing plans to reach about 120 GW and 440 GW



Wind and solar capacity growing at about 50–60 GW annually to reach over 800 GW each

Incentivize investment

- Continuation of the subsidy-free regime for solar/wind interconnect at the coal benchmark price
- Continued use of auctions to ensure intense competition
- Incentives for long-term private contracts

Mobilize flexibility resources

- Better wholesale markets for short-term energy trading
- Opened markets for all participants
- Coordinated and flexible inter-provincial dispatch
- A technology-neutral capacity market
- Transparent data disclosure

Upgrade planning

- Comprehensive and granular load forecasts
- Grid infrastructure to align with VRE growth

Enhance reliability

- Effective markets for ancillary services
- Technical regulations upgrade

- This should be reflected in broad quantitative targets for renewable energy capacity over the next 10 years, in line with the Zero-Carbon Investment Scenario, with wind and solar capacity growing to around 1,650 GW by 2030. This implies capacity growth of wind and solar combined of approximately 110 GW per annum.

- End-year targets for the 14th Five-Year Plan should be compatible with the 10-year objective, broken down into year-by-year objectives and with requirements set on a province-by-province basis.

Four key pillars of policy are required to ensure that these targets are achieved:

Policies to achieve delivery

- Continuation of the subsidy-free regime for solar/wind interconnect at the coal benchmark price. Contracting at coal benchmark price for onshore wind and solar will generate an increasing premium for new projects, incentivizing rapid deployment in the near term.

- Continued use of auctions to ensure intense competition. China should also consider the use of competitive auctions for specified quantities of wind and solar development, giving successful bidders a certain fixed price for a significant share of their generation. Auctions of this sort should be deployed to the extent that other delivery policies are insufficient to meet provincial targets.

- Incentives for long-term private contracts. Private long-term supply contracts (PPAs) should be enabled allowing end-users to contract with developers. This would supplement publicly organised auctions by leveraging private power users who have set aggressive sustainability targets.

Market and grid reforms to support flexible power

- Better wholesale markets for short-term energy trading. Inadequate price signals and economic incentives currently result in less flexible thermal and hydro operation than possible. A greater role for short-interval day-ahead and real-time markets could better reflect the output variations from VRE and stimulate all system resources to respond to the system needs by following the price signal.

- Opened markets for all participants. Both short-term energy markets and ancillary service markets should be open to all types of technology. Having closed markets can undermine market effectiveness and result in suboptimal dispatch. It can also impede the development of new technologies that will be increasingly needed to balance the system as zero-carbon shares grow to high levels beyond 2030.

- Coordinated and flexible inter-provincial dispatch. Inflexible interprovincial contracts and incentives make achieving balance more difficult. Policies to address this should:
  - Expand the balancing zones and developing a coordinated cross-system dispatch; and
  - Allow inter-provincial trading to respond to short-term provincial price signals and balancing dynamics (versus today's system in which prices and volumes are scheduled on an annual basis).

- Transparent data disclosure. Diverse market participation and fair competition could drive innovation and lower costs of flexibility provision; this requires equal access to information, such as load profile and load forecast. But with a few major players currently owning and controlling proprietary data, new participants have found it difficult to compete effectively. Thus, it is important to set industry data disclosure standards, including data types, granularity, and disclosure frequency.

- A technology-neutral capacity market. Well-functioning energy markets could themselves provide adequate incentives for flexibility (and should be the priority), but the increasing role of flexible resources could also be remunerated via markets for capacity provision. But any such capacity markets should be "technologically-agnostic" to ensure incentives for the development of the full range of zero-carbon storage options (e.g., batteries or hydrogen), which will be increasingly required over time.

Improved power planning processes to support VRE integration

- Comprehensive and granular load forecasts. The data that utility/grid companies currently publish on load patterns, which often show only a single average annual peak load number, can create a bias toward thermal investment and against other storage or peak supply options.

- Grid infrastructure to align with VRE growth. As VRE penetrates, it is critical to align grid upgrade planning at both transmission levels and distribution levels with long-term quantitative targets for growth in renewable capacity. In addition, transparent disclosure of methodologies for assessing future renewable integration capability will equip developers with visibility to develop long-term development plans and lower non-technical costs of renewable energy development.

Technical and market actions to support short-term grid management

- Effective markets for ancillary services, such as very short-term frequency balance. As with short-term energy market and capacity markets, these should be developed on a "technology-agnostic" basis.

- Technical regulations upgrade. Technical requirements, grid connection rules, and processes should ensure system stability in the face of growing renewables shares, covering in particular the following:
  - Improved forecasting of VRE output to prevent avoidable renewable curtailment and reduce unnecessary system reserves
  - Tighter grid regulations on wind farm ramping to reduce steep wind output variation and resulting system impacts
  - Mandatory requirements for HVRT to enhance VRE's performance during system disturbance and avoid cascading failure
  - Careful quantification and management of system inertia to ensure system reliability as VRE penetration grows

The key to achieve President Xi Jinping's carbon neutrality target by 2060 is to fully decarbonise the power system. Thus, the top priority for the next decade is to ensure that all power growth is coming from zero-carbon generating capacity. Our analysis suggests that zero-carbon power growth in China over the next decade is not only a necessary task, but also technically and economically achievable.

ENDNOTES

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