

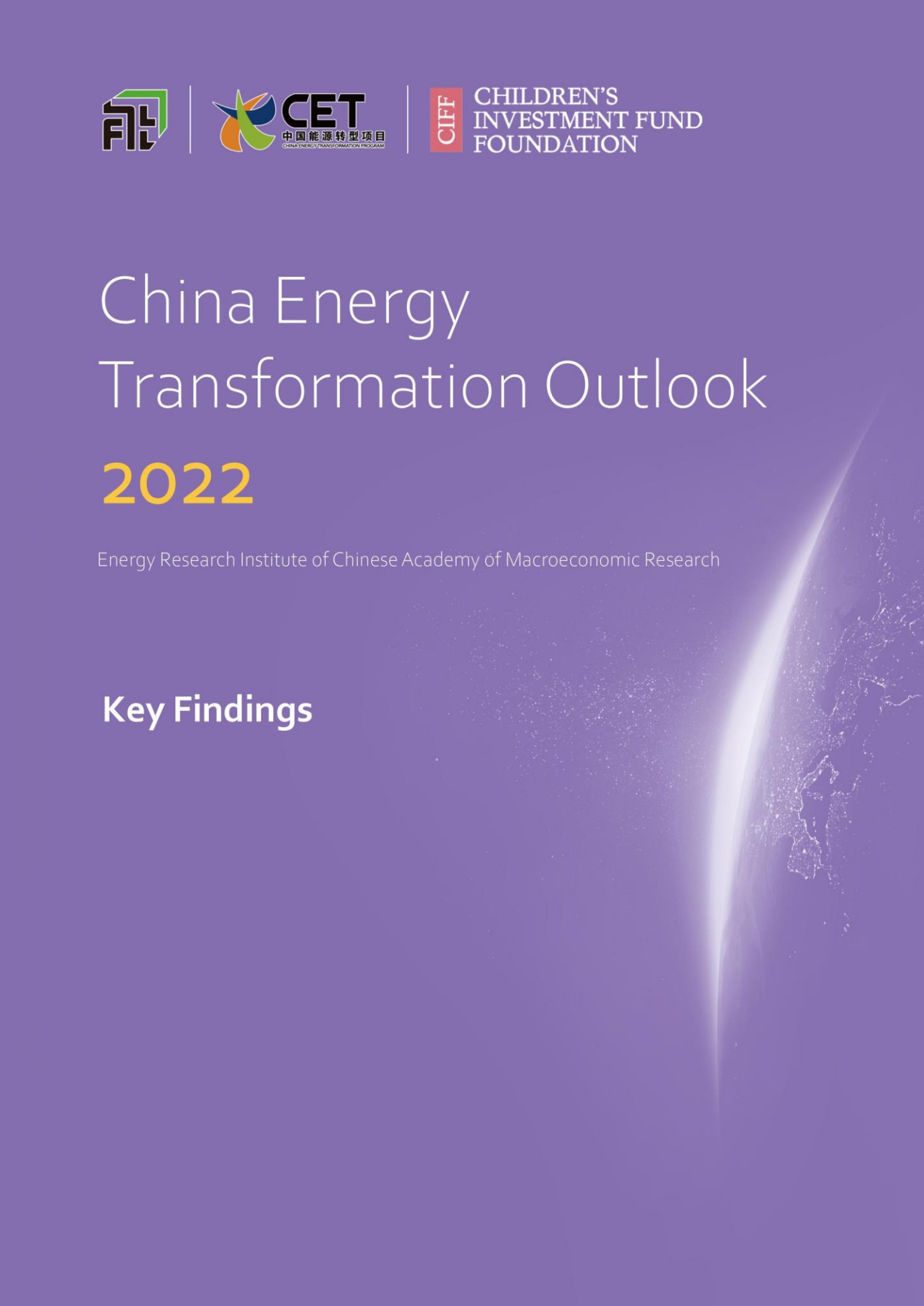


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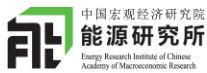
China Energy Transformation Outlook 2022

Energy Research Institute of Chinese Academy of Macroeconomic Research

Key Findings



Implementing Unit



Financial Support



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The views and opinions expressed in this report are those of the CETO project team and solely for research purposes, but do not necessarily reflect the views and positions of any individual partner institute. Unless otherwise indicated, the data is derived from the CETO modelling database and analysis.

"China will strive to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060. This requires tremendous hard work, and we will make every effort to meet these goals."

President Xi Jinping

**Statement at the General Debate of the 76th Session of
the United Nations General Assembly, September 2021**

Preface

China has set up clear ambitions to implement a profound energy transformation. With the statement from President Xi Jinping on 22 September 2020, China has significantly stepped up the commitment to strive to peak CO₂ emissions before 2030 and achieve carbon neutrality before 2060. Thereby the previous commitment to a green development pathway has been reconfirmed. President Xi has introduced the new energy security strategy featuring Four Reforms for improving the energy consumption structure, building a more diversified energy supply structure, improving energy technologies to upgrade the industry, and optimising the energy system for faster growth of the energy sector, and One Cooperation, which is international cooperation to achieve energy security in an open environment. The 19th National Congress of the Communist Party of China further promotes the ambitions to build a clean, low-carbon, safe and efficient energy system.

While the climate goals are clear, the pathways for the energy transformation call for clarification. The energy transformation must achieve multiple objectives aside from climate goals. China is still in the developing phase of economic development. The energy transformation should support the overall economic growth and ensure a just transformation, considering the destruction and creation of jobs and local challenges in transitioning from fossil fuels to clean energy. Furthermore, the transformation must balance the urgent need for CO₂ emission reductions with time to develop new technologies, new policy instruments, and a genuine penetration of the transformation policies into all layers of decision-makers.

This year's China Energy Transformation Outlook, CETO 2022, focuses on two different energy system scenarios for energy transformation. The first is the baseline scenario, where China contributes to the global 2-degree goal and achieves carbon neutrality around 2070. The other scenario shows a path to meet the climate targets to peak CO₂ emissions before 2030 and reach carbon neutrality before 2060. Also, the report includes several thematic analyses, including end-use transformation, power sector transformation, power market reforming, power-to-X, carbon pricing, status and prospects of CCUS in China.

I want to thank the ERI team for their strong efforts, the Danish Energy Agency, the Center for Global Energy Policy, Columbia University, and the Norwegian NORAD for their strong support and input to the analyses, and, not least, our long-term cooperation partner, Children's Investment Fund Foundation (CIFF), for funding and support to ERI, which made it possible to prepare this outlook report.

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Key findings

The foundation for China's energy transformation

China is today at a crossroads for the development of the energy system. Summing up the history of China's energy and economic development since the reform and opening up, the principal contradiction in energy development has changed. For an extended period, the principal contradiction was between the insufficient supply of total energy and the need for economic and social development. Today, the contradiction is between the high-carbon structure of energy supply and sustainable economic and social development. The central aspect of the conflict has also changed, from ensuring the supply of coal to meet the shortage of total supply in the past to vigorously developing renewable energy sources such as wind, solar and hydro energy to optimise the energy supply structure and promote the transformation of the energy system into a low-carbon or even zero-carbon system.

China's roadmap for energy development is a choice between the old roadmap and the new roadmap. The old path is the so-called successful path that other countries have already taken, including several developed nations: from coal to oil and gas, followed by a switch from oil and gas to renewable energy. This path contains several problems: It is too slow to meet the Paris Agreement requirements. It will jeopardise the security of energy supply and environmental safety, and it sets the economy under severe risks due to the international demand for low-carbon produced goods. Furthermore, China risks missing the innovation opportunity related to green development, and the energy system will become more costly and needed in the medium and long term.

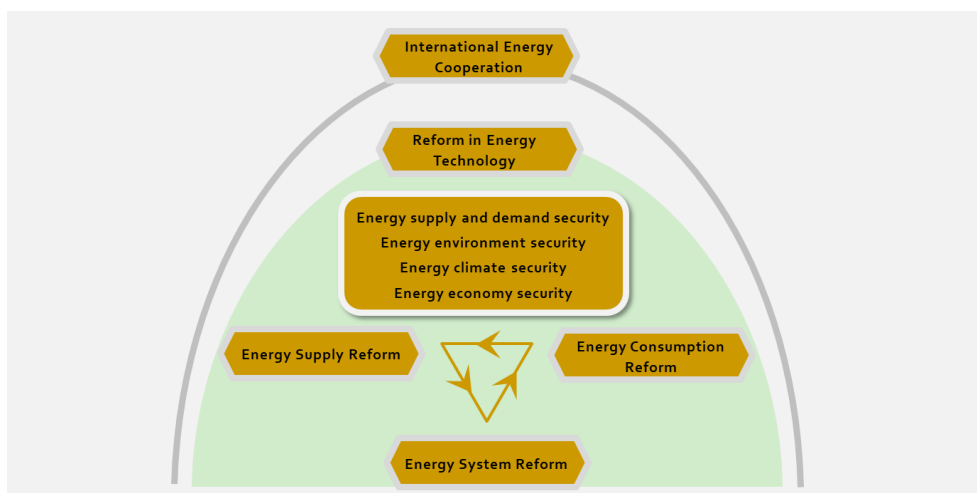
In contrast to the old path, China must follow the new roadmap introduced by the 19th CPC National Congress¹: Build a clean, low-carbon, safe and efficient energy system as the core feature of a modern energy system. The energy development aims to achieve a sustainable balance between these features and even end up with a system where these features mutually reinforce each other. Hence, China must return to the energy security strategy of "Four Reforms and One Cooperation" proposed by the General Secretary in June 2014ⁱ. The strategy includes an energy consumption revolution as the key element, with an energy supply revolution as the foundation for the development.

The core of this "key" and "foundation" is to make energy production and energy consumption form an organic and seamless connection, which means that the green energy produced can be delivered to the consumer at any time and that the consumers prefer green energy instead of "black" energy. Production and consumption form a market cycle, and the effective interface between production and consumption and the proper functioning of the market needs to be supported by a revolution in the energy

ⁱ The new energy security strategy featuring Four Reforms and One Cooperation was put forward by Xi Jinping at the conference of the Leading Group for Financial and Economic Affairs under the CPC Central Committee held on June 13, 2014.

system. However, whether it is the energy production revolution, the energy consumption revolution, or the energy system revolution, none of them can be implemented without support from the technological revolution, which should be an efficient guarantee for the above three revolutions. In addition, under the general trend of global economic integration, the goal of building a community of common human destiny, and the irreversible trend of green and low-carbon transformation of global energy, no country or even enterprise can do it alone and needs to carry out extensive international cooperation in energy.

Figure 1: The internal logic of the Four Reforms and One Cooperation



The construction of a modern energy system is closely related to peak carbon dioxide emissions and achieving carbon neutrality and is a complex system project. As the General Secretary pointed out at the ninth meeting of the Central Finance and Economics Commission on 15 March 2021, "achieving peak carbon and carbon neutrality is an extensive and profound economic and social systemic change."²

Therefore, constructing a modern energy system also requires a systemic energy transformation. As long as China adheres to the general policy of "Four Reforms and One Cooperation", it is expecting to be able to complete the systemic energy transformation, build a modern energy system, and ultimately achieve energy supply and demand security, energy environment security, and energy climate security, thus guaranteeing national economic security.

The CETO scenarios

The scenarios in CETO comprise two development pathways for the Chinese energy system. The *Baseline Scenario* (BLS) shows a development, where China contributes to the global 2-degree goal and achieves carbon neutrality around 2070. A *Carbon Neutral Scenario* (CNS) illustrates the pathways for achieving the dual goals of peaking carbon dioxide emission before 2030 and achieving carbon neutrality before 2060.

The CETO scenarios provide a detailed outline of key components that should define China's Energy Transformation Strategy and the approach to achieving carbon neutrality.

This relies on four pillars and the last resort:

- **Energy efficiency** improvement on the demand side is needed to ensure the pace of supply-side deployments can keep up and sustain required economic growth.
- **Green energy supply** – technological progress and cost reduction make RE provide clean energy in bulk, mainly through renewable electricity.
- **Electrification** will support driving fossil fuels from end-use consumption, in conjunction with the decarbonisation of the electricity supply.
- **Hydrogen** becomes a vital energy carrier, which links the abundant supply of cheap green electricity and the hardest to abate sectors. Green hydrogen, combined with captured carbon, allows for creating fuels for heavy transport, shipping, and aviation sectors.
- **Sequestration** of CO₂ creates the backstop or last resort option, particularly with negative emissions and carbon sinks. Negative emissions can compensate for a modest level of emissions still in the system in 2060 (e.g., from incomplete capture of fossil plants with CCS).

To achieve carbon neutrality in practice, each of the above pillars relies on the previous. Without energy efficiency, the necessary pace of supply-side scale-up of green energy will require excessive capital, and the cost of useful energy services is expected to be too high. Without a green electricity supply, electrification will only move emissions sources from end-use sectors to fossil-fuelled power plants. The hydrogen and PtX pathways are likely the more costly supply-side transformations and should serve the harder to transition demand-side transformations. Finally, intensive direct and indirect electrification creates opportunities for large-scale electricity consumption, which has a significantly higher potential for flexible operation than traditional costly and alternative storage options such as hydrogen or in consumption side batteries. The electrification process, which requires a green electricity supply, can provide the lynchpin making the necessary final increments of high penetration variable renewable energy (VRE) possible in the power sector.

Key results for the two scenarios

Continued economic growth can be supported while achieving carbon neutrality

The scenarios show the pathway for the transition of the energy system to a clean, low-carbon, secure and efficient energy system. The energy needed to support continued economic growth can be secured by promoting energy efficiency, electrification, and massive renewable energy deployment.

Energy efficiency improvement is a key pillar to drive down the overall energy demand

Despite a more than 4.2-fold increase in real GDP between 2020-2060, the final energy consumption can return to current levels by 2060. In both scenarios, the economy's energy intensity decreases to less than 23% of the 2020 level by 2060.

Electrification transforms the demand side

Direct fossil fuel consumption decreases in favour of electrification. Most significantly, the direct use of fossil fuels is switching to electricity in industry, transport and buildings sectors.

Renewable energy satisfies the bulk of the energy demand

The cost reduction of renewable electricity, the practical completion of market reforms, and the ability to scale up manufacturing allow wind and solar power to become the backbone of the energy system.

Power-to-X, carbon sequestration and carbon sinks are necessary to achieve the final steps towards carbon neutrality

China can reach a low-carbon energy system with a solid effort to improve energy efficiency, electrify the end-use sectors, and deploy renewable energy on the supply side. However, to reach carbon-neutrality, it is necessary to develop and deploy the power-to-X technologies, especially the production of green hydrogen, and remove CO₂ by sequestration and carbon sinks. These technologies play an increasing role in the energy system after 2035.

Policy recommendations

To achieve the carbon neutrality target by 2060 and establish a clean, low-carbon, safe, and efficient energy system, it is necessary to promote industrial electrification, green electricity, and the informatisation, digitisation and intelligence of the energy sector. Firstly, large-scale development and use of green electricity is key to the supply-side reform of the energy sector, facilitating the foundation of a new energy system; secondly, promoting the informatisation, digitisation and intelligence of the energy sector will support the energy sector's green, low-carbon transition; thirdly, optimising energy production should be guided by the end-use energy demand.

Take the large-scale use of green power as a breakthrough point, drive and conduct the modernisation and transformation of China's energy system

China should accelerate promoting wind and solar power to become the major power sources, and increasing green electricity supply. Both utility-scale and distributed onshore wind power should expand orderly, accompanied by the construction of power transmission lines and the amelioration of the power consumption market. Specifically, it is planned to orderly construct utility-scale wind bases in the Three-North and the middle provinces. Distributed wind power should be widely applied and used better due to the continuous advance of related technologies. In addition to meeting the demand for

clean energy within the region, more inter-regional deployment of wind power is planned. Utility-scale solar farms are expecting to expand continuously, and the layout of these needs to be optimised. The development of solar power should be planned and performed from a broader view. China should continue to construct more solar farms for inter-regional power transmission in resource-desirable regions, and for improving comprehensive land-use efficiency.

The energy transition towards renewable power should be coordinated with coal and gas power. It is important to improve conventional power regulation capabilities. To balance the interplay of competition and cooperation between coal power and renewable energy and green electricity means that the overall green, low-carbon transition, the control of total coal consumption, and the supply-demand reform of the energy sector should be considered as a whole system. Electric power industries and companies must shoulder more responsibility in this green electricity transition. We need to make good use of the existing coal power resources and accelerate the transformation of coal power flexibility by adding high-efficiency heat storage facilities to coal power plants to adapt to the rapid fluctuations of power system load and renewable energy generation, improving the flexibility of coal power, and shifting the role of coal power from the main bearer of the baseload to the provider of system flexibility. The completion rate of flexibility retrofit carried by existing coal power units should reach over 50% by 2025, and 100% by 2030. Better use of the coal power reduction and replacement, and the regulating function of gas power in window periods, can provide firm support for developing the high-penetration renewable energy system in the northwest and the distributed energy system in northern, eastern, and southern China.

To build a unified, open, and orderly competitive energy market system: a trading platform for coal, electricity, petrol, and natural gas enables the dynamic interaction between supply and demand; building a power market system including medium- and long-term trading, spot trading, and other ancillary services trading is a big step for founding the national power market and national carbon market. Improving the green certificate system by optimizing the trading methods, pricing and management involved in the green electricity and power certificate transactions and making it coordinate well with the carbon market.

The energy storage system development goal mainly focuses on pumped storage, electrochemical batteries, electric vehicles, and green hydrogen. Various energy storage technologies with different temporal and spatial characteristics enable the development of an overall “renewable energy + storage” system. Storage systems are not only the basic component of the on-grid renewable power plants in western regions, where wind and solar resources are desirable, but also the main regulating method of the grid for system inertia support, emergency power support, voltage regulation, etc., participating in the power ancillary service market independently or together with other regulating power sources.

Take the informatization, digitization and intelligence of the energy sector as accelerators to catalyse the modernization and transformation of the energy system

Big data, 5G, artificial intelligence, Internet of Things and other new technologies boost the informatization, digitization and intelligence of the energy sector. As technologies keep progressing and cost continues to reduce, leading companies and their intellectual resources will play a key role in improving the competitiveness in offshore wind power and distributed solar power industries. The expanding applications of smart grid, energy Internet, and energy storage, as well as a better distributed market-oriented power trading mode, will make the whole energy system become more efficient and convenient. The development of core cutting-edge technologies, such as new energy vehicles and new energy industries, will spread the new energy industry chain both upstream and downstream, effectively promoting the high-quality development of the energy sector.

It is important to improve the green smart grid planning. Grid planning needs to be coordinated with power supply construction and load development, balancing the large-amplitude and high-frequency fluctuations on supply and demand side. China aims to develop utility-scale and distributed energy in parallel and emphasize on both local and inter-regional clean energy consumption, thus optimizing the allocation of clean and low-carbon energy from a broader view. Power grid planning must be considered nationwide: from establishing a multi-layered national interconnection system from the intra-province balance at top-priority, to regional coordination, and to the broader national balancing dispatch. Intelligence technologies can efficiently assist grid operation and management, with the help of which the grid can better accept and configurate power from multiple energy sources and meet various requirements from supply and demand-side users.

Guide the continuous optimization of energy production with end-use energy and electricity demand, and continue to promote the realization of the carbon neutrality target

Electrification and green electricity substitution in end-use sectors can improve energy efficiency and reduce CO₂ emissions. Using green electricity substitution to boost the modernization and electrification in industry, transportation, building, and other end-use sectors is a practical path to improve the energy consumption structure and reduce pollution. There are several possible ways to achieve this plan: simultaneously promoting renewable energy production and electric vehicles; focusing on coal reduction and electrification in high-polluting industries, and in urban and rural commercial and residential buildings; expanding the capacity of urban and rural gas power and heat supply infrastructure and integrating it with distributed renewable energy. The goal of the energy revolution will be realised when every citizen can enjoy sustainable energy.

The active response on the demand side is another key element. China needs to improve the load-side response mode based on price incentives, formulate a pricing system that reflects the supply and demand of the market, improve and promote peak and valley pricing mechanisms on both the generation and user sides, and improve demand-side

power management. China also needs to integrate system operating conditions, market transactions, and user consumption data into a comprehensive management system and use big data technologies to analyse the load-side data to enhance the load-side responsive capabilities. There are also strong practical needs for expanding the application of V2G, accelerating the construction of electric vehicle charging infrastructures, and innovating the interactive technology and business model of electric vehicle charging and discharging. Further, China should consider how to re-use retired batteries for storage and explore the potential to synchronize the life cycle of electric vehicle batteries with renewable energy generation.

Finally, hydrogen substitute through electrolysis has been put on the agenda. In the future, hydrogen produced through electrolysis will play a pivotal role in connecting all kinds of renewable energy. It is necessary to start constructing hydrogen-electricity infrastructures in suitable locations. China strives to make independent breakthroughs in hydrogen industry technologies such as green hydrogen production, long-distance hydrogen transportation and end-use applications. Hydrogen production through electrolysis will gradually become the major consuming method for wind and solar power in the western region. Due to the expected decline in the cost of green hydrogen, the downstream application market of hydrogen energy will spread from the transportation sector to the energy storage, industrial, and building sectors, forming an electric-hydrogen combining industry system.

Additional key findings from the Outlook research

Carbon pricing

Adding a cost for CO₂ emission (carbon pricing) is an important policy instrument in the overall climate policy framework. China launched a national carbon emissions trading system (ETS) in 2021 after a decade in the making. This market-based mechanism is supposed to provide incentives for low-carbon technology and drive emissions reduction, contributing to China's decarbonization pathway to 2060. In addition to the emissions trading system, other types of carbon pricing schemes such as carbon tax could similarly be introduced and play their roles in driving the transformation.

At the start, China national ETS adopts an intensity-based target, in contrast to the absolute emissions target in other Cap and trade schemes. Thermal power plants are given certain numbers of allowances based on a predetermined benchmark for their fuel type and capacity category (emissions intensity, in ton CO₂/MWh). Thus, ageing and inefficient thermal plants are punished if their emission intensity is above the benchmark since they need to buy allowances for compliance. On the contrary, more efficient thermal plants will have surplus allowances as subsidies, since they can sell in the carbon market and get revenue.

There is a limitation for an intensity-based target. Even though it can improve the overall efficiency of the thermal power fleet (mainly coal), it indeed provides incentives for building new and more efficient plants whose emission intensity are below the

benchmark. Moreover, the ETS emissions will rise as long as total output (thermal power generation) increases. With China set to peak CO₂ emissions, it is necessary to bring the ETS target in line with the overall emissions target. This implies that national ETS shall quickly move to an absolute emissions reduction target in order to drive down emissions in the ETS-covered sectors, fulfilling the 2030 CO₂ peak goal. The government could define the contribution of the ETS into the overall climate target.

In addition to switching from an intensity-based target, national ETS shall also gradually introduce auctioning of allowances, and reduce the free allocation of allowances. The revenues from auctioned allowances could be used as funding for investments and innovation in low-carbon technology.

As carbon pricing provides incentives for renewables investments, it is valuable to ensure the consistency and synergy between carbon pricing and RE support policies.

Power to X in China

Power-to-X (PtX) encompasses numerous energy conversion pathways and a broad range of output fuels, energy forms, chemicals and even foods. In CETO, a comparative study investigates how the energy systems in two provinces could serve as a PtX production base. Qinghai is a province with considerable VRE resources and with large potential to deploy these at low cost. Guangdong is a load centre, industrial hub, aviation hub, and not least a key location for international shipping. Guangdong has hydrogen development included in its 14th FYP with a focus on “clean-energy-based” hydrogen production and chemical by-product hydrogen sources.

The analysis is carried out by integrating OptiFlow, an open source for representing networks of interconnected processes, with the EDO model representing the power and district heating supply in the CETO scenarios.

Key takeaways from the case studies

Even future PtX conversion pathways are likely to involve significant conversion losses along with an increased demand for electricity and heat. Therefore, to reduce CO₂ emissions, only decarbonised electricity should be used for PtX and it should not be utilised in sectors where direct electrification is economically feasible.

Different provinces require different solutions. In a comparison of two provinces:

- A provinces access to biogenic carbon, market for PtX products and power system characteristics are relevant for which PtX products should be prioritised.
- To reduce CO₂ emissions, large-scale PtX production should not take place in a province until it can be assured that the additional electricity demand is produced from CO₂ free sources.

In the future, PtX solutions can deliver an important tool in a decarbonising society. The above findings underscore the need for taking a system perspective in this decarbonisation effort, with PtX pathways being reserved for sectors that are the most

difficult to electrify. Quantitative studies are required to guide 1) Where and when to build large scale PtX facilities, and 2) Prioritise and quantify the different PtX products based on the CO₂ intensity of the fuels replaced and economic feasibility.

Status for CCS and CCUS in China

As the world's largest energy consumer and carbon emitter, China has long recognized carbon capture, utilization, and storage's (CCUS) potential to allow the country to utilize fossil fuel while simultaneously achieving deep carbon emissions reductions. In the past decade, the Chinese central government released at least 26 CCUS-related policies, focusing on both technology R&D and industrial demonstrations. Against the backdrop of China's climate pledge of peaking carbon dioxide emissions before 2030 and achieving carbon neutrality before 2060, CCUS policies in China become increasingly proactive and supportive.

The overall mitigation impact of CCUS in China has been limited so far, despite the technology in carbon capture and breakthroughs in geological utilization. Between 2007 and 2019, China reached a cumulative carbon dioxide (CO₂) storage volume of 2 million tons (Mt).

Unlike other net-zero emissions technologies such as energy conservation, renewables-based electrification, bioenergy, green hydrogen, and enhancement of biological sinks, the Achilles' heel of CCS deployment is the lack of auxiliary benefits other than carbon emissions abatement, which makes it difficult to take decisions in near-term actions. It is crucial that CCUS development does not lead to a noticeable reduction of nationwide efforts to support energy conservation, renewable and other clean energy development, both in R&D and financial terms. In absence of major technological breakthrough, CCUS should be positioned as the "last resort" backup technology to decarbonize hard-to-abate sectors where no viable alternative is available.

China should aim: 1) to further improve quality of energy and emissions statistical reporting; 2) to establish supportive and comprehensive CCUS regulations and standards; 3) to eliminate all fossil fuel subsidies to stimulate market penetration of net-zero emissions technologies including CCUS in the domestic front; 4) to proactively work with the EU and other like-minded countries with net-zero emission targets to explore a multilateral instead of unilateral solution for carbon leakage protection in the international front.

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