CHILDREN'S INVESTMENT FUND FOUNDATION

China Energy Transformation Outlook

2021

Energy Research Institute of Chinese Academy of Macroeconomic Research

Executive Summary

Implementing Unit

Financial Support

Technical Support

"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

Table of Contents

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 CO_2 emissions before 2030 and achieving 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 energy consumption, energy supply, energy technology, and the energy system, and One Cooperation, which is an international cooperation to achieve energy security under open conditions. 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, taking into account destruction and creation of jobs and local challenges in the transition from fossil fuels to clean energy. Furthermore, the transformation must balance the urgent need for CO_2 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.

With this first China Energy Transformation Outlook, CETO 2021, The Energy Research Institute, Chinese Academy of Macroeconomic Research, is moving into a more comprehensive analysis of the Chinese energy system than in the previous China Renewable Energy Outlooks. The CETO 2021 focuses on two different energy system scenarios for energy transformation. The first scenario 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 CO_2 emissions before 2030 and reach carbon neutrality before 2060.

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.

Wang Zhongying

Director-General, Energy Research Institute of
Chinese Academy of Macroeconomic Research

The world needs to solve the climate crisis

In August, Working Group 1 of the Intergovernmental Panel on Climate Change (IPCC) released its contribution to the Sixth Assessment Report[1]. The IPCC working group finds it is "unequivocal that human influence has warmed the atmosphere, ocean and land." The working group also finds that the scale of recent changes in the climate "is unprecedented over many centuries to many thousands of years" and that "human-induced climate change is already affecting many weather and climate extremes in every region across the globe."

Global roadmaps by the IEA[2] and IRENA[3] show pathways for reducing energy sector emissions 40-45% by 2030 and achieving net-zero emissions from the energy sector by 2050. The two studies show that achieving net-zero emissions is possible.

The Emissions Gap Report 2021 from UNDP[4] shows that new national climate pledges combined with other mitigation measures put the world on track for a global temperature rise of 2.7°C by the end of the century. That is well above the goals of the Paris climate agreement and would lead to catastrophic changes in the Earth's climate.

---

[1] "Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change," Intergovernmental Panel on Climate Change, accessed at https://www.ipcc.ch/report/ar6/wg1/.
[2] "World Energy Outlook 2021," International Energy Agency, accessed at https://www.iea.org/reports/world-energy-outlook-2021.
[3] "World Energy Transitions Outlook: 1.5°C Pathway," International Renewable Energy Agency, June 2021, accessed at https://irena.org/publications/2021/Jun/World-Energy-Transitions-Outlook.
[4] "Emissions Gap Report 2021: The Heat Is On – A World of Climate Promises Not Yet Delivered," United Nations Environment Programme, 2021, accessed at https://www.unep.org/resources/emissions-gap-report-2021.

The foundation for China's energy transformation

China is today at a crossroad 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 main contradiction in energy development has changed. For a long period, the main 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 Congress[5]: To 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 2014[6]. The strategy includes an energy consumption revolution as the key element, with an energy supply revolution as the foundation for the development.

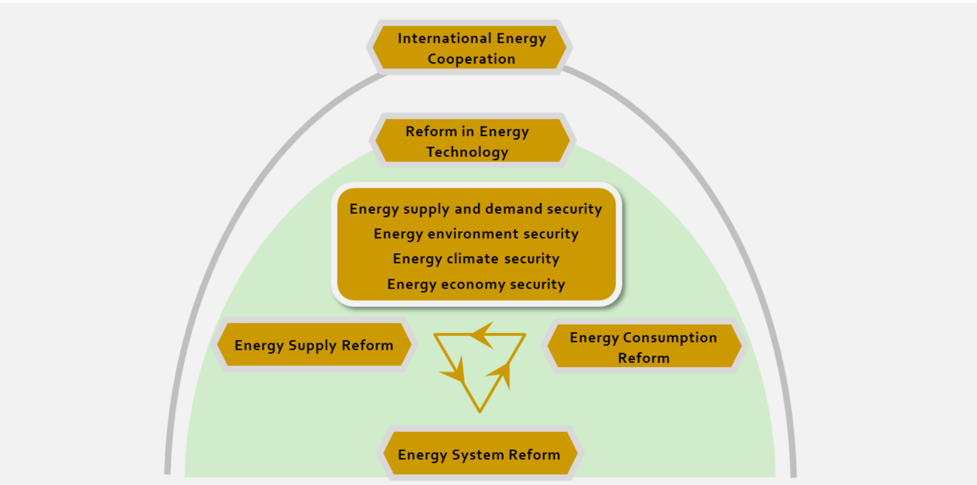
The core of this "key" and "foundation" is to make energy production and energy consumption form an organic and seamless connection, which means that the green energy produced can be delivered to the consumer at any time and that the consumers prefer green energy instead of “black” energy. Production 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 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

[5] “Full text of Xi Jinping's report at 19th CPC National Congress,” Xinhua, 3 November 2021, accessed at http://www.xinhuanet.com/english/special/2017-11/03/c_136725942.htm.

[6] 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.

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."[7]

Therefore, the construction of a modern energy system also requires a systemic energy transformation. As long as we adhere to the general policy of "Four Reforms and One Cooperation", we will 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.

[7] "习近平主持召开中央财经委员会第九次会议," China News, 15 March 2021, accessed at https://www.chinanews.com/gn/2021/03-15/9432980.shtml.

The Chinese energy system pathway to Carbon Neutrality

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.

Main findings

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. The energy intensity of the economy decreases to 23% of the 2020 intensity by 2060 in both scenarios.

Electrification transforms the demand side

Direct fossil fuel consumption decreases in favour of electrification. Most significantly, the direct use of fossil fuels is transitioned in industry and transport, but also building energy consumption is electrified. Overall, the electrification rate increases from 27% in 2020 to 54% for the Baseline scenario and 74% for the Carbon Neutrality scenario in 2060.

Renewable energy will satisfy the bulk of the energy demand

The cost reduction of renewable electricity, and the effective completion of market reforms and the ability to scale-up make wind and solar power core to the energy provision. The share of renewable energy in the primary energy consumption will grow from 13.5% in 2020 to 87.6% in the BLS and 92.8% in the CNS in 2060. The share of non-fossil fuel energy (renewables and nuclear) in the primary energy consumption will grow from 15.7% in 2020 to 91.2% in BLS and 96.8% in CNS in 2060. All shares are based on the coal substitution method.

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 strong effort to improve energy efficiency, to electrify the end-use sectors, and to deploy renewable energy on the supply side. To reach carbon-neutrality, it is however necessary to develop and deploy the power-to-X technologies, especially production of green hydrogen, and to remove CO_2 by sequestration and carbon sinks. These technologies will play an increasing role in the energy system after 2035.

The CETO scenarios

The CETO scenarios provide a detailed outline of key components which 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 able to provide the clean energy in bulk, particularly through renewable electricity.
- **Electrification** and will support driving fossil fuels from end-use consumption, in conjunction with decarbonisation of the electricity supply.
- **Hydrogen** becomes an important energy carrier, which creates the link between the abundant supply of cheap green electricity and the hardest to abate sectors. Green hydrogen, combined with captured carbon, allows for the creation of fuels for difficult to abate sectors such as some heavy transport, shipping, and aviation.
- **Sequestration** of CO_2 creates the backstop or last resort option particularly with negative emissions as well as 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).

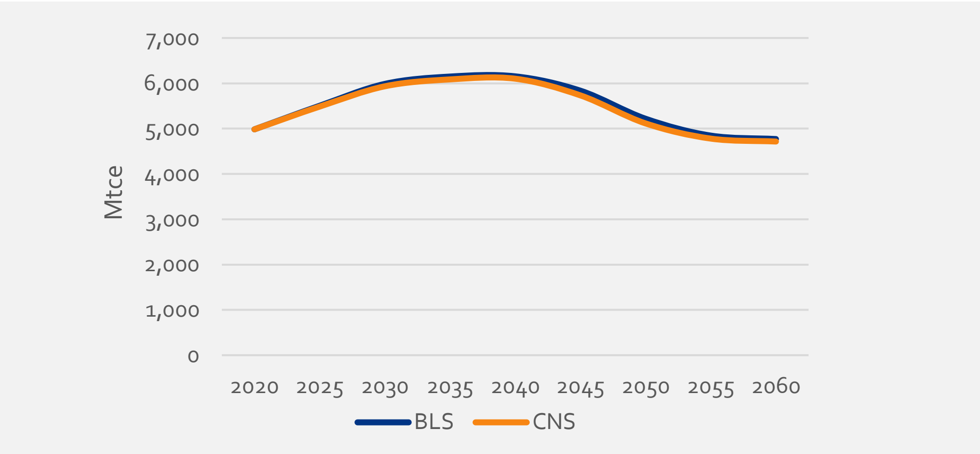
To achieve carbon neutrality in practice, each of the above pillars relies on the previous. Without energy efficiency, the necessary pace of supply side scale-up of green energy will require excessive amounts of capital and the cost of useful energy services will be too high. Without green electricity supply, electrification will only serve to 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 therefore mainly 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, as well as alternative storage options as hydrogen or in consumption side batteries as examples. Thereby, 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

Primary energy consumption trend

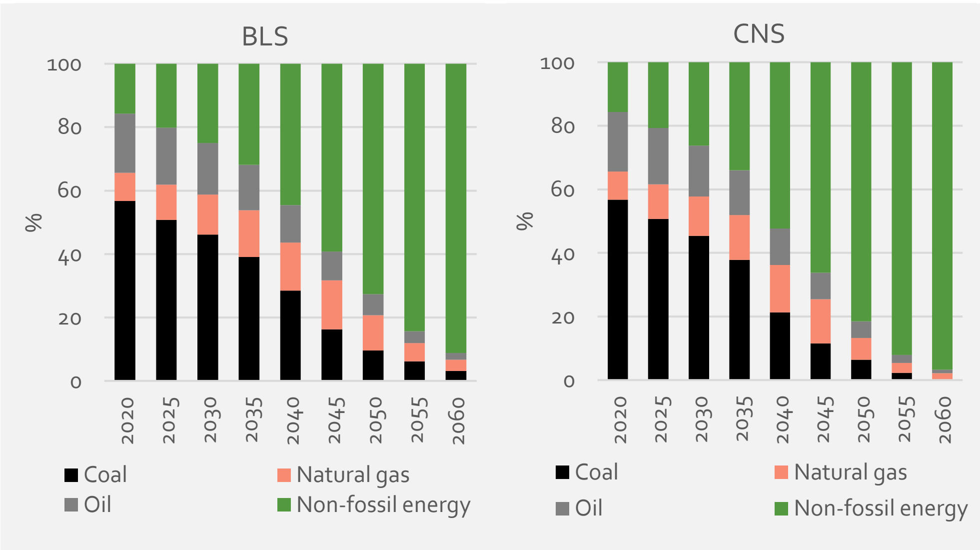
As a result of the different drivers for the energy transformation, the total primary energy consumption (TPEC) will peak around 2040 in both scenarios, with an almost identical development trend in the two scenarios.

Figure 2: Total Primary Energy Consumption (Mtce) in the two scenarios 2020 – 2060 (Coal Equivalent Calculation)



In both scenarios, non-fossil fuels and natural gas gradually substitute coal from 2020. In 2035, non-fossil fuels cover 32% of the total primary energy consumption in BLS and 34% in CNS. In 2050, the share is 73% in BLS and 82% in CNS. In 2060, the share is 91% in BLS and 97% in CNS (Coal Equivalent Calculation).

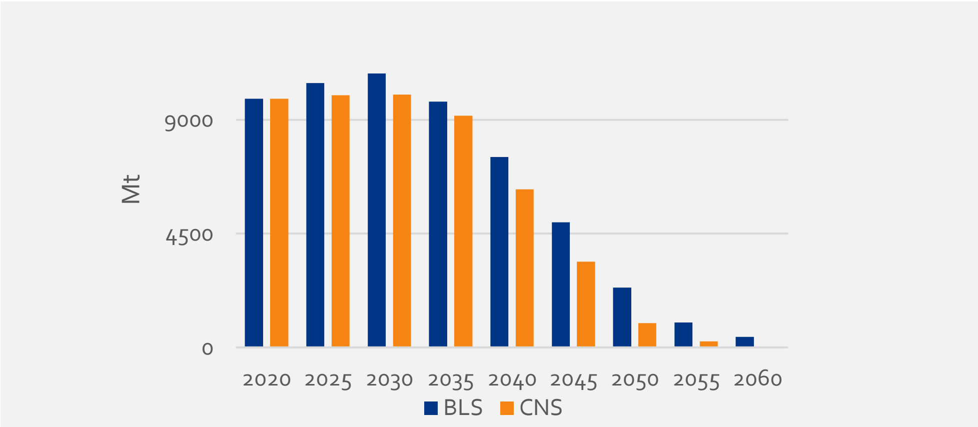
Figure 3: Fuel shares in the Total Primary Energy Consumption (%) (Coal Equivalent Calculation)



CO_2 emission peak before 2030

The CETO scenarios show that it is possible to have a CO_2 peak before 2030 for the Chinese energy sector, as shown in Figure 4. The CNS has a lower CO_2 emission throughout the period to 2060 compared with the BLS. The CNS reaches carbon neutrality before 2060, while the BLS still has CO_2 emission. However, both scenarios have a steady decrease in CO_2 emission after 2030.

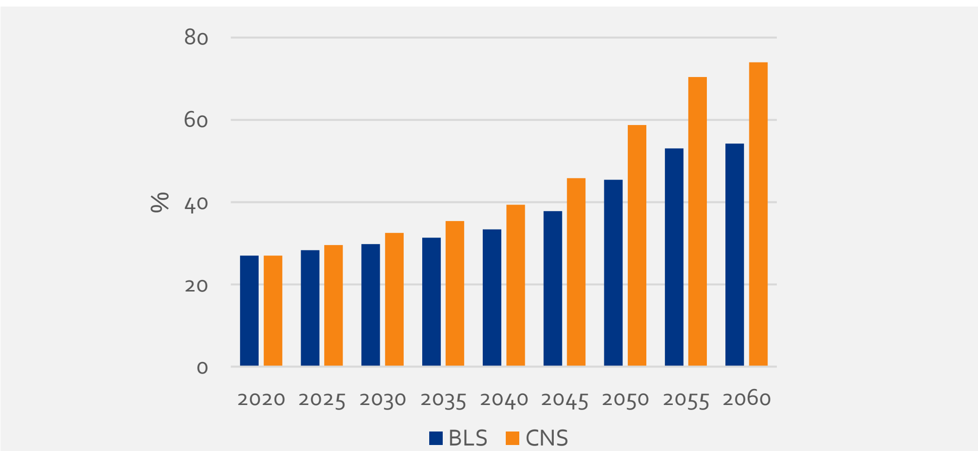
Figure 4: Energy sector CO_2 emissions in the CETO scenarios from 2020-2060 (million tons)



Electrification strategy decreases coal and oil in the end-use sectors

An essential part of the energy transformation is to substitute fossil fuels in the end-use sectors with electricity from a green power system. Furthermore, the introduction of green hydrogen produced by wind and solar power is an indirect way to electrify the end-use sectors. With the deepening of industrial electrification (especially the iron industry) and the promotion of electric vehicles, electricity consumption will increase substantially. In 2060, the general electrification rate in the end-use sectors reaches 54% in the BLS and 74% in the CNS.

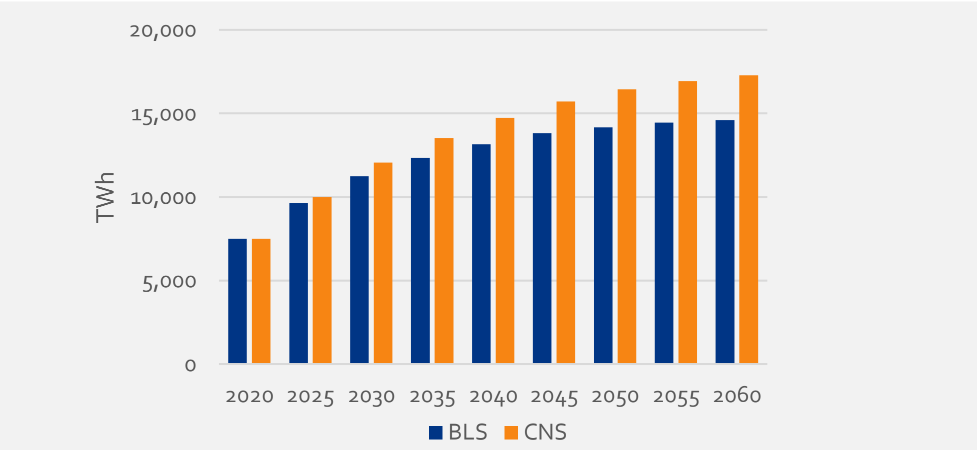
Figure 5: Electrification rate (%) development 2020 – 2060 in the BLS and CNS



Electricity consumption keeps increasing trends in both scenarios

Under both scenarios, China's total electricity consumption shows an upward trend, while the electricity consumption is generally higher in the CNS than in the BLS due to the more ambitious electrification of the end-use sectors. In the CNS, the total electricity consumption reaches 12,000 TWh in 2030 and further to 17,300 TWh in 2060, suggesting a twofold increase in total power consumption from 2020 to 2060.

Figure 6: Electricity consumption in the two scenarios (TWh)

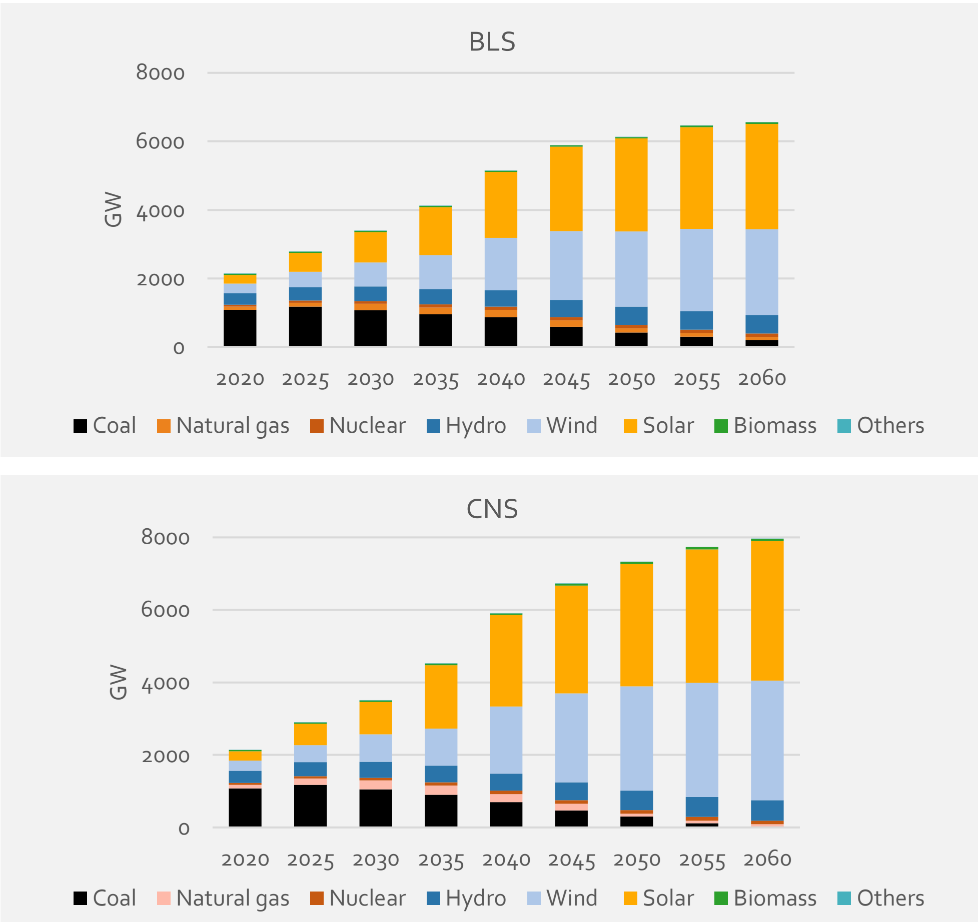


Solar and wind power make the power sector green and clean

The CNS has 760 GW of wind power and 890 GW of solar power to a combined 1,650 GW by 2030, and the total installed capacity of wind power and solar PV is thereby higher than the target of 1,200 GW. This is mainly due to the economic competitiveness of wind and solar compared with other technologies, combined with the target to have a CO_2 peak before 2030. The BLS has 707 GW of wind and 880 GW of solar installed in 2030.

By 2060, the cumulative installed capacity of wind and solar further increases to 7,145 GW in CNS, of which 3,300 is wind power and 3,845 is solar power. The BLS has 2,500 GW of wind and 3,070 GW of solar installed in 2060.

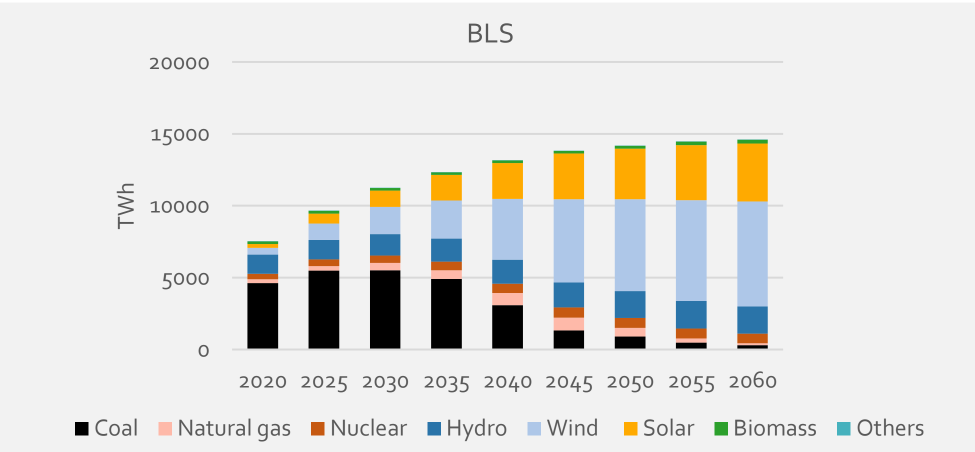
Figure 7: Installed power capacity in the two scenarios (GW)



Renewable power will dominate power generation mix in the long-term future

In both scenarios, the total electricity generation grows in the period towards 2060, doubling from around 7,500 TWh in 2020 to almost 14,600 TWh in 2060 in the BLS, and has an increase to 17,300 TWh in the CNS. Coal-based power production is gradually phased out and replaced by electricity from renewable energy, mainly solar PV and wind turbines. The share of renewables in power production increases from nearly 30% in 2020 to 92.5% in 2060 in the BLS scenario and 95.5% in the CNS.

Figure 8: Power generation in the two scenarios (TWh)



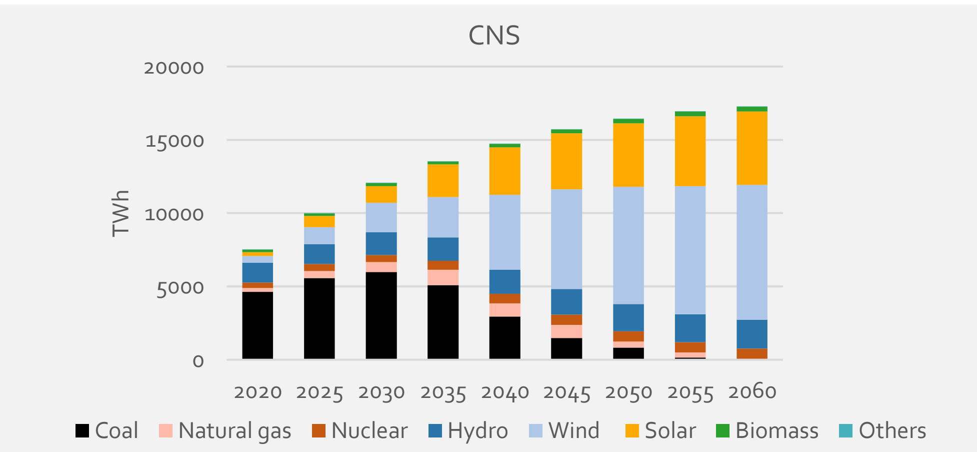


Figure 9: 2020 China Energy Flow Chart (Mtce) in CNS

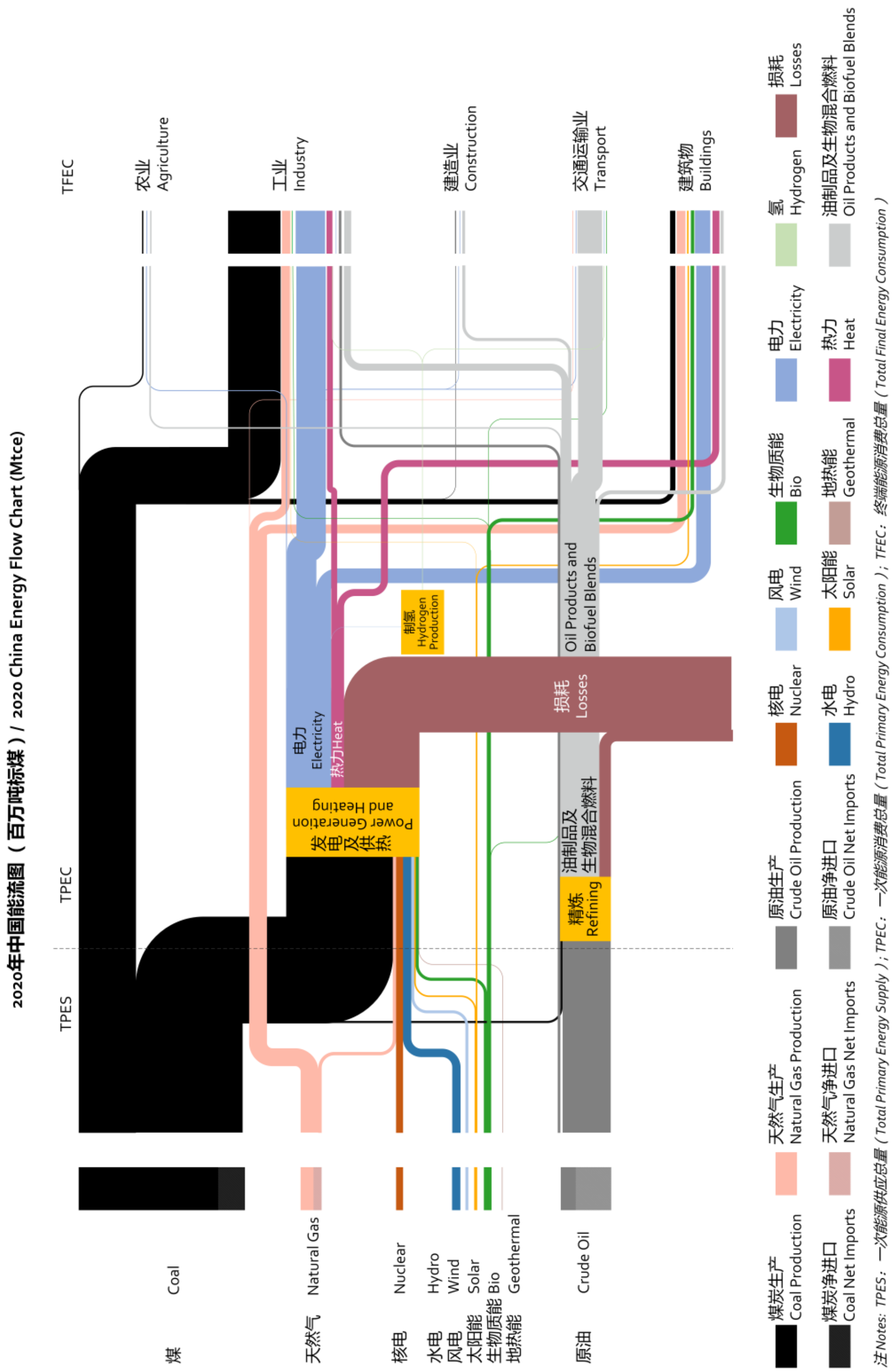
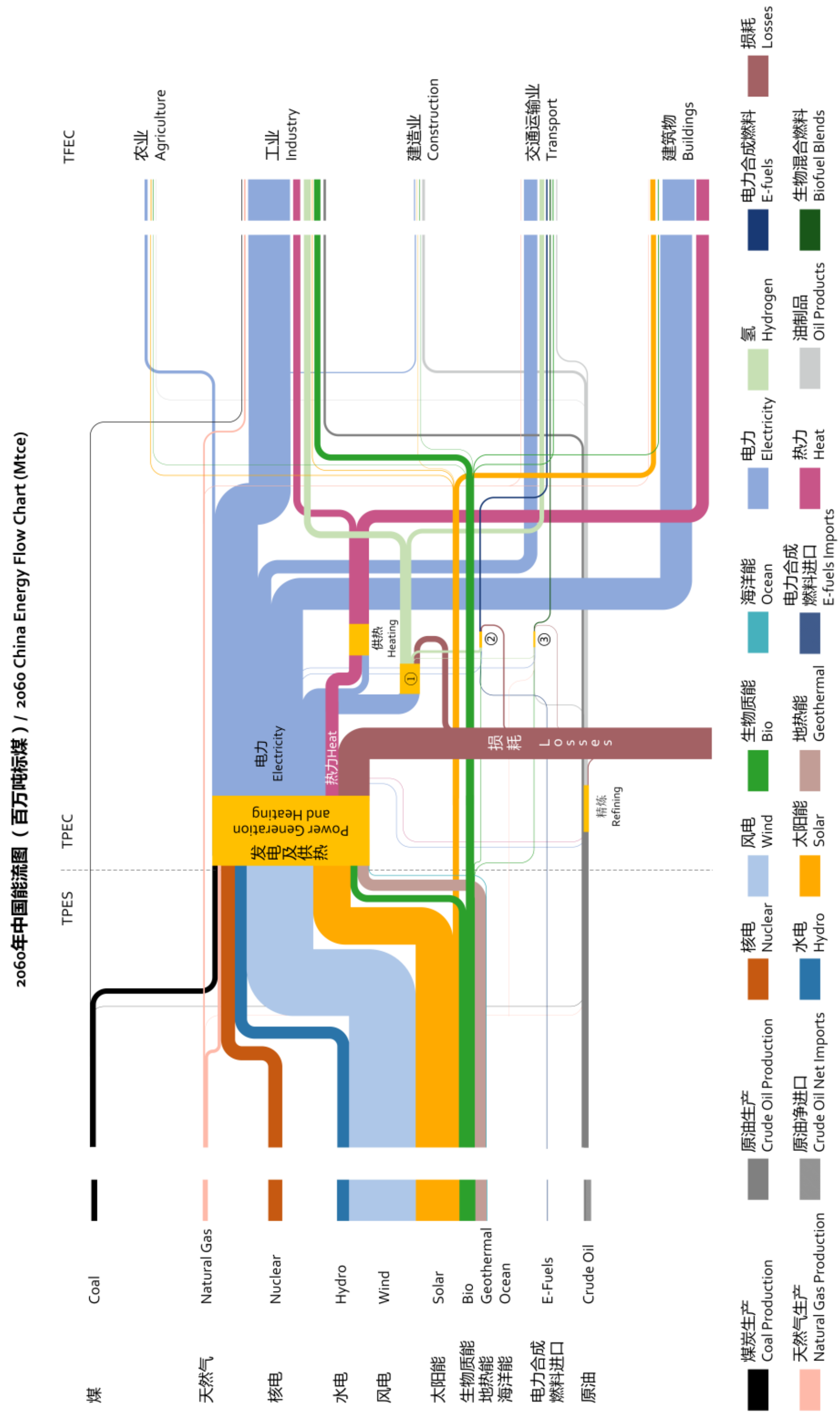


Figure 10: 2060 China Energy Flow Chart (Mtce) in CNS



注Notes: ①制氢 Hydrogen Production；②制电力合成燃料 E-fuels Production；③制生物混合燃料 Biofuel Blends Production

TPES：一次能源供应总量（Total Primary Energy Supply）；TPEC：一次能源消费总量（Total Primary Energy Consumption）；TFEC：终端能源消费总量（Total Final Energy Consumption）

More complex dispatch operation and shifted balancing paradigm

With a large penetration of variable renewables, system operating paradigms shift towards covering the variability of renewable production by providing more flexibility in the operation. On both power generation side and consumption side, various flexible sources, including storage, V2G, load shifting, and EV charging are mobilized to accommodate the power system fluctuation caused by a high share of variable renewables. The share of mobilized power consumption becomes larger.

Figure 11: Hourly power balance in China's power system for 2060 winter in the CNS

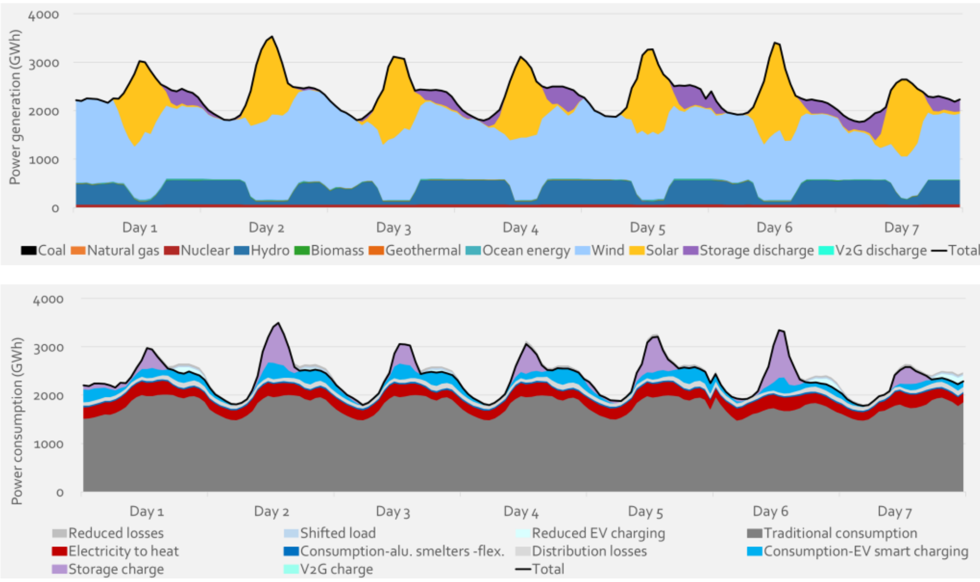
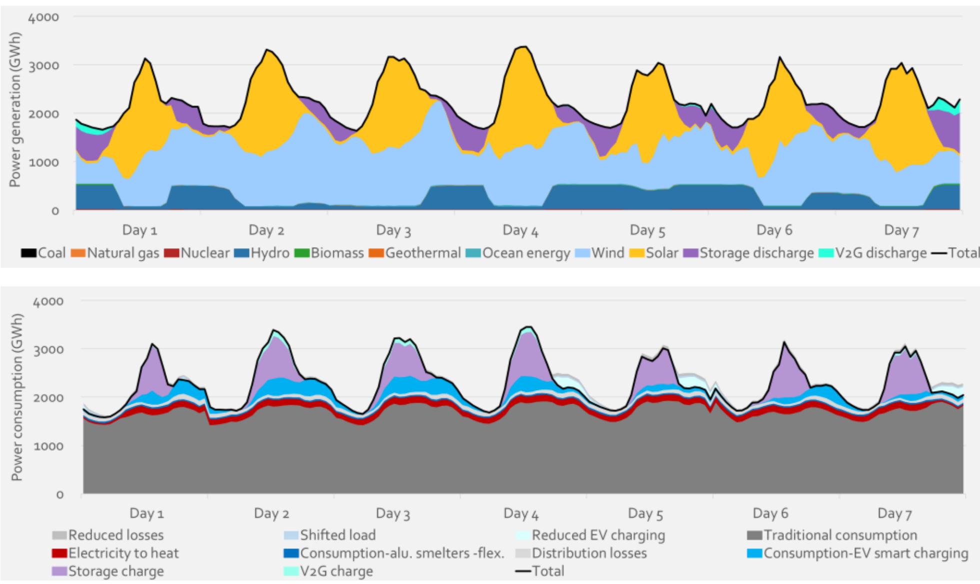


Figure 12: Hourly power balance in China's power system for 2060 summer in the CNS



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 informatization, digitization 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 informatization, digitization and intelligence of the energy sector will support the energy sector’s green, low-carbon transition; thirdly, optimizing energy production should be guided by the end-use energy demand.

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

China accelerates to promote wind and solar power to become the major power sources, and to increase green electricity supply. Both utility-scale and distributed onshore wind power will be expanding 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 will be widely applied and used better due to the continuous advance of related technologies. In addition to meeting the demand of clean energy within the region, more inter-regional deployment of wind power is planned. Utility-scale solar farms will be expanding continuously, and the layout of these will also be optimized. What is more, the development of solar power should be planned and performed from a broader view. China will 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 will 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 have to 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 base load to the provider of system flexibility. The completion rate of flexibility retrofit carried by existing coal power units will 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 a 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 will not only be the basic component of the on-grid renewable power plants in western regions, where wind and solar resources are desirable, but also be 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 must 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 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 CO_2 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 definitely be realized when every citizen can enjoy sustainable energy.

The active response on the demand side is another key element. We need 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 generation and user side, and improve demand-side power management. We also need to integrate system operating conditions, market transactions, and user consumption data to 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, we should consider how to re-use retired batteries for storage and explore the potential to synchronize the life cycle of electric vehicle batteries with the 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 the 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 CO_2 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 CO_2/MWh). Thus, aging and inefficient thermal plants will be 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 (CO_2) 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.

ERI's energy system modelling tool

The scenario's development is supported by the ERI's energy system modelling tool, consisting of interlinked models covering the energy sector of China.

Final energy demands are directed in the END-USE model

Based on the Long-range Energy Alternatives Planning system, LEAP, the END-USE model represents bottom-up models of end-use demand and how this demand is satisfied. Assumed developments in key activity levels specified for each subsector and the economic value added for where no other driver is available drives the consumption in the end-use sectors. These drivers translate to energy consumption when combined with assumptions, as well as end-use behavioural features adjustment. Transformation and resource activities aside from district heating and power are also covered by LEAP, including upstream refinery activity.

EDO models the Power and district heating sectors

The EDO (Electricity and District heating Optimisation) model is a fundamental model of power and district heating systems built on the Balmorel model. The power system is represented at the provincial level, considering the interprovincial grid constraints and expansion options. The model includes thermal power (including CHP), wind, solar (including CSP), hydro, power storage, heat boilers, heat storages, heat pumps, etc. It also considers demand-side flexibility from industries, options for charging electric vehicles and the option of a fully integrated coupling with the district heating sector.

The model can represent the current dispatch in the power system on an hourly basis, including technical limitations on the thermal power plants and interprovincial exchange of power, as well as the dispatch in a power market, provincial, regional or national, based on the least-cost marginal price optimisation. Key characteristics relate to the detailed representation of the variability of load and supply (e.g. from VRE sources) as well as flexibility and flexibility potentials, which can operate optimally and be deployed efficiently in capacity expansion mode.

Combined summary tool

Results from the two models are combined in an integrated tool, which provides an overall view of the energy system, combining fuel consumption from the power and heating systems from EDO with direct consumption in end-use sectors and other transformation sectors from LEAP.

China Energy Transformation Outlook

2021

Executive Summary