China Energy Transformation Outlook 2023 (CETO 2023) Summary

How to read the China Energy Transformation Outlook 2023

This report is a short summary of the full *China Energy Transformation Outlook 2023* (CETO 2023) report. The full report consists of three parts.

Part I gives a brief overview of the global climate crisis and the global energy development situation in Chapter 1, focusing on recent years' development. It also provides a status for the development of the Chinese energy system and for the energy policy in China in Chapter 2.

Part II is the modelling-based scenario analysis[1] of the Chinese energy system transformation towards 2060. It consists of four chapters: Chapter 3 summarises the overall transition situation of the energy system, including the framework design and assumptions of the three scenarios included in the Outlook. Chapter 4 dives into the energy consumption pathways in the end-use sectors, including the industry sectors, the building sector, the transport sector, and other sectors. Chapter 5 details the analysis of the power sector based on results from the power sector model. Chapter 6 analyses the socio-economic impact of the energy transformation.

Part III includes six thematic chapters unrelated to the modelling-based scenario analysis in Part II. Chapter 7 describes the energy security policies and current situation in China. Chapter 8 analyses an overview of the latest developing progress in carbon pricing in China. Chapter 9 describes the progress related to methane emissions control globally and in China. Chapter 10 analyses trends and case studies of local and regional energy transformation. Chapter 11 summarises the energy and climate policy developments in Denmark. Chapter 12 discusses the significance of green financing to the energy transition.

[1] Unless there is a specific note, the data for the four chapters in Part II (including the base year data) of the report are based on the CETO database and calculation of the CETO model.

The summary gives the highlights of the analyses in the Outlook report, including the key findings from the scenario analyses in Part II. The summary can be read as a separate document from the full report. The four chapters in Part II describe the overall conclusions and specific findings of the CETO scenario analyses in detail. Here, it is possible to dive into the details to understand the outlook scenario design and the detailed conclusions by sector. Each of the chapters in Part III can be read independently of the rest of the Outlook to gain insight into each topic.

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Feedback to the Outlook is most welcome. Please send your feedback to ceto2023@cet.energy.

CETO 2023 full report (Chinese)

CETO 2023（中文）

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CETO 2023 (English)

CETO 2023 Key scenario results and recommendations

Three energy system scenarios

The starting point for *China Energy Transformation Outlook 2023 (CETO 2023)* is China's commitment to achieving carbon neutrality before 2060. Compared with previous low-carbon development targets, achieving peak carbon and carbon neutrality represents a more extensive and profound systemic transformation of the economic and social systems. Fulfilling this commitment requires significantly improved energy efficiency, a rapid expansion in non-fossil fuel energy, and carbon sinks or negative emission technologies to realise comprehensive carbon neutrality.

Within the framework of the "1+N" policy system for peaking carbon emissions and reaching carbon neutrality, CETO 2023 examines energy system transformation scenarios across various end-use sectors and the processing and conversion sector, with a focus on the feasibility and pathways to achieve the carbon neutrality milestone. Utilising the LEAP, EDO, and CETPA models, the research team has analysed end-use energy consumption, power and heat supply, and the subsequent environmental and societal impacts. The team then conducted a coordinated analysis of multiple goals, including economic development, carbon reduction, and energy security. The overarching perspective acknowledges that China's energy transformation should not only champion carbon goals, but also foster economic development and uphold living standards under the initiative for Building Beautiful China, culminating in the Chinese-style modernisation of harmonious coexistence between humanity and nature. Building a new-type energy system, with new power systems at its core, that is clean, low-carbon, secure and resilient, flexible and smart, highly efficient, inclusive, and shared, is crucial for achieving peak carbon and carbon neutrality.

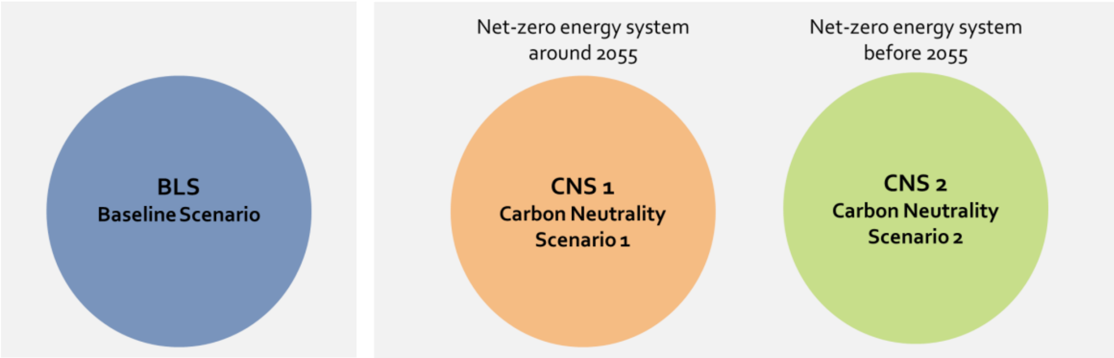
CETO 2023 defines three scenarios for China's energy path leading up to 2060:

The Baseline Scenario (BLS) is developed by projecting current trends in energy system development and is calibrated to align with the objective of the *Paris Agreement* to limit the global average temperature increase to within 2°C this century. The analysis incorporates considerations of prevailing political and economic tensions across the globe, alongside newly proposed policies from key regions and countries. It assesses the likely impacts on the evolution of new and renewable energy sectors, as well as on the energy transition both globally and within China. A Baseline Scenario for China's energy transformation, characterised by relatively lower intensity, is presented. This serves as a standard for quantitative comparisons with two scenarios that envisage full carbon neutrality.

Two Carbon Neutrality Scenarios (CNS) operate under the supposition that the countries of the world unite and make concerted efforts to achieve the goal determined by the *Paris Agreement*, that is, to "hold the increase in the global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels". The two carbon neutrality scenarios set the forcing targets for China of peaking carbon emissions before 2030 and achieving carbon neutrality before 2060, but there are differences in the choices of pathways and timing for the energy system to achieve net zero emissions.

The Carbon Neutrality Scenario 1 (CNS1): Advocates for renewable energy development, and by 2055, biomass power and remaining coal and gas power units are fully installed Carbon Capture, Utilisation and Storage (CCUS) facilities, targeting net zero emissions in the energy system around 2055.

Carbon Neutrality Scenario 2 (CNS2): Based on advocating renewable energy development, it is required to expand wind and solar PV power generation capacity further. The full load hours and power generation of coal power units both drop faster till naturally retired as a consequence. Prior to 2055, the biomass power and remaining gas power units are gradually installed as CCUS facilities, aiming for net zero emissions in the energy system before 2055.



Key findings of the scenario analyses

The scenario analyses can be summarised in the following key findings:

The global energy and climate situation calls for an accelerated global energy transformation. Both carbon neutrality scenarios (CNS1 and CNS2) show that **China's green and low-carbon transformation of the energy system can enable carbon neutrality by 2060.** CNS1 foresees net-zero emissions in the energy system around 2055, while CNS2 anticipates this before 2055. Concurrently, by 2060, China's economy quadruples its 2021 size, yet primary energy consumption is just about 60% of its 2021 level.

The BLS presents a reference scenario where energy transformation challenges and uncertainties escalate due to the unpredictability and deepening alterations in global political and economic spheres. Herein, fossil fuel use dips post-2030 but doesn't plummet significantly by 2060, underscoring the imperative for robust global policy cohesion to hasten energy system transformation.

Significantly improved energy efficiency is the premise and basis for achieving carbon neutrality, and it is essential to achieve a substantial level of electrification in end-use sectors to facilitate a green and low-carbon transformation of the energy sector. Comprehensive improvement of energy efficiency in end-use sectors and the energy supply sector can reduce total energy consumption and decouple economic growth from growth in energy demand. Hence, China's energy efficiency needs to improve continuously. A substantial level of electrification and the expansive development of hydrogen production within the end-use sectors are key drivers for accelerating the growth in electricity consumption. Electrification in the industrial, transportation, and building sectors helps reduce fossil fuel consumption in end-use sectors. The shift from thermal power generation to wind and solar power generation in the power sector can reduce energy processing and conversion losses in the supply sector. In CNS2, by 2060, while China's economic scale grows about fourfold, final energy consumption and primary energy consumption drops to 64% and 56% of the 2021 level, respectively ; the electrification rate of end-use sectors reaches 66%, and the total electricity consumption reaches 20,200 TWh.

Leapfrog development of renewable energy plays a pivotal role in shaping new power systems, marked by extensive growth in wind and photovoltaic power generation. In both the CNS scenarios aiming for net-zero emissions in the energy system, renewable energy's share in the primary energy supply surpasses 74% by 2060. The power system undergoes a comprehensive clean transformation, with renewable energies like wind and photovoltaic power emerging as the predominant sources. This shift leads to a significant increase in installed capacity, transforming renewable energy into an inexpensive and plentiful low-carbon resource. By 2060, renewable energy contributes over 94% of the total electricity production, with the remaining coming from nuclear energy. This shows that under the premise of coal power transformation, the deep decarbonisation of the energy mix and comprehensive transition towards non-fossil energy sources are imperative prerequisites for achieving net-zero emissions in the energy system.

The role of coal power is evolving from a baseload source to a more flexible power source. With the right technical backing, both CNS1 and CNS2 suggest that the yearly operating hours of these coal-fired units diminish over their operational life, leading to a more cost-effective energy system transformation. This strategic approach not only considers growth and safety but also moves towards achieving net-zero emissions in China's energy landscape. In this transformation, coal-fired power's role evolves, and its full adaptability for flexibility is achieved by 2040. After 2040, as the active units near their end-of-life, these coal-fired units begin phasing out, with their operating times sharply dropping to under 1,000 hours. Post-2050, coal-fired power generation in both CNS scenarios reduces to an exceedingly low level. The broader power infrastructure moves away from coal as its primary energy source. However, select decommissioned units are preserved and maintained, standing by as emergency backups.

Nuclear power plays an active and stable role as a low-carbon baseload power source. In all scenarios, nuclear power capacity grows consistently, reaching an estimated 120 GW by around 2040. Positioned along the country's coastlines, these installations operate as baseload units with a high number of operation hours.

As the growth in natural gas demand decelerates, its role in energy consumption is gradually adjusted. Scenario analyses indicate that the swift advancement of renewable energy enables China to bypass a period of high growth and dependence on oil and gas. In the power sector, factors such as the rapidly declining costs of wind and solar power generation, the relatively high price of natural gas, and the transition of coal-fired power units to peak shaving in the short to medium term collectively impede the growth of natural gas demand for power generation. Instead, natural gas is primarily utilised in end-use sectors. Additionally, the development and implementation of biomass gas in sectors like power generation, industry, and transportation could supplant some of the natural gas demand. In all three scenarios, the share of natural gas in the total primary energy demand decreases to less than 7% by 2060.

To establish a novel type of power system, comprehensive coordination and balancing of the system is essential, alongside constructing a highly intelligent new grid. Developing new-type energy storage, demand response, and smart energy systems are pivotal for maintaining power system security. The robust development of renewable energy within this new energy system continues to refine the grid structure, leading to an innovative grid pattern characterised by "West-East Power Transmission, East-West Power Cooperation, North-South Power Transmission, and South-North Power Interconnection." Integrating large-scale, fluctuating renewable energy sources effectively is crucial to satisfy future power users' needs, particularly during peak demand times. Emerging energy storage solutions, such as electrochemical storage, vehicle-to-grid (V2G) integration, and compressed air energy storage, complement traditional pumped storage stations and peak regulation reservoirs, progressively supplanting the peak-regulating roles of coal-fired plants. From 2021 to 2035, in the CNS2 scenario, the new-type energy storage technologies growth at an average annual rate of 26%, showcasing exponential expansion. Between 2030 and 2060, V2G's widespread adoption is anticipated, growing at an annual average rate of about 14%. By 2060, pumped storage, new energy storage, and demand-side response emerge as the primary regulatory resources of the power system, with electric vehicle storage playing a crucial role in ensuring its stable operation. Moreover, green hydrogen, while rising as a source to facilitate industrial transformation, contributes to balancing the power system load, primarily through the flexible production of hydrogen.

Carbon capture and storage (CCS) emerges as an important, albeit "last resort", tool for realising carbon neutrality. The primary application of CCS technology is to mitigate carbon emissions from those sectors that are challenging to decarbonise, CCS also could additionally aid in curbing emissions from coal and gas power plants. Pairing biomass power generation with bioenergy carbon capture and storage (BECCS) introduces an innovative approach to achieving a net-zero emission power system.

However, leaning heavily on CCS technology for carbon neutrality presents substantial risks. Scenario analyses indicate inherent technical limitations with CCS, and the potential pitfalls of over-reliance on it warrant careful consideration. To start, the CCS processes of capturing, compressing, transporting, and storing carbon demand significant energy and heat. This consumption hampers the efficiency of coal and gas power facilities, inadvertently causing further carbon emissions and amplifying the demands on the CCS system. Moreover, achieving complete carbon capture is elusive, even for plants equipped with advanced CCS. Thus, to truly attain carbon neutrality, alternative carbon removal strategies, such as the pricier direct air capture (DAC) technology or forest carbon offsets, become necessary. This implies that achieving a net-zero carbon footprint in the energy system remains challenging. Furthermore, the geologic prerequisites for CCS are stringent. Questions remain about the potential long-term leakage of stored CO_2, necessitating more extended research and experimental validation. The repercussions on local subterranean and surface ecosystems also require comprehensive assessment.

Green hydrogen serves a dual-purpose role as both a zero-carbon feedstock and fuel. The development and deployment of green hydrogen hold immense promise for sectors that are notoriously difficult to decarbonise, like steel and petrochemicals. Hydrogen can serve as a reducing agent, substituting the requisite coke in the iron smelting process and as a raw material, replacing coal in the production process of synthesising ammonia. Beyond that, hydrogen offers a viable replacement for fossil fuels like petrol and diesel in transportation. Additionally, hydrogen paves the way to produce other electrofuels (PtX), offering alternative fuel options for aviation and shipping. Across various projections, the appetite for hydrogen keeps growing, accompanied by a surge in related electricity consumption.

The shift towards green and low-carbon energy is essential for ensuring sustainable social and economic advancement in China. Meeting the targets of carbon peak and carbon neutrality necessitates comprehensive and deep-rooted systemic changes, with energy transformation being a key component. The swift and groundbreaking progress in clean energy technologies is pivotal in not only stimulating the growth of green industries but also in creating a greater number of green employment opportunities, while substantially reducing the source emissions of air pollutants. This energy transformation is crucial in providing a secure and efficient energy supply while concurrently aiding in the modernisation of industries, propelling high-quality economic development, and supporting the achievement of varied sustainable development objectives.

China energy flow charts

Figure 1 2021 China energy flow chart

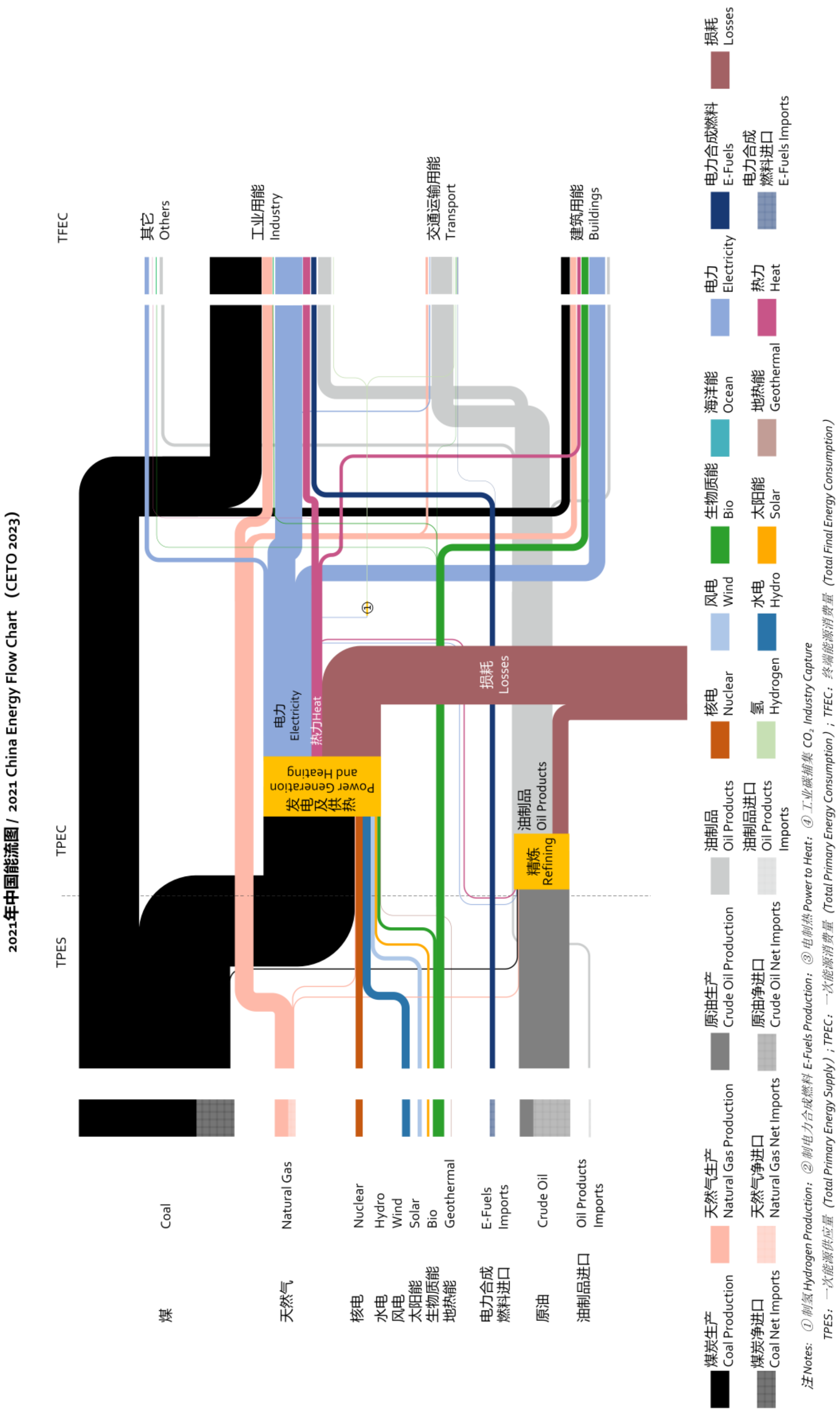


Figure 2 2060 China energy flow chart – CNS2