China Energy Transformation Outlook

2023

Energy Research Institute of Chinese Academy of Macroeconomic Research

Special Report for COP27

Addressing New Global and Domestic Challenges and Advancing Firmly Towards the Net Zero Energy Transformation Goal

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 21, 2021

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Preface

In the wake of unprecedented changes that are set to shape our world, our times and our history, human society is facing challenges that we have never seen before. The challenging issues of climate change and energy are further augmented by a wide array of new developments in the international geopolitical arena. Against this backdrop, we must waste no time taking a more determined stance in forging global consensus, acting collaboratively to push forward the energy transformation, and actively addressing climate change.

Since establishing an energy partnership in 2005, China and Denmark have engaged in extensive intergovernmental cooperation in the energy sector. Both countries believe in green growth and are committed to green energy transformation. This COP27 Special Report provides an in-depth summary and discussion of the results of the energy transformation in both China and Denmark and their respective efforts to address the challenges of climate change.

In his speech at the UN General Assembly General Debate in September 2020, President Xi Jinping announced that China will scale up its intended Nationally Determined Contributions by adopting more vigorous policies and measures and aim to reach a peak in carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060.

Seeing carbon emissions reduction as a profound economic and social change, China has since last year issued a series of policy system documents, known as the "1+N" policies, to realise the carbon-peak and carbon-neutrality targets. Individual implementation plans supplement these overarching policies to achieve carbon peak in critical areas and industries, including plans for the green energy transformation action, the industrial carbon peak action, the green and low-carbon transportation action, and circular economy carbon reduction action, as well as a variety of supporting and safeguard measures in the fields of science and technology, carbon sink, finance and taxation, and banking. These policy measures, on the one hand, intensify the development of clean energy comprising mainly solar and wind energy and speed up the green and low-carbon transformation of conventional energy sectors; on the other hand, they help broaden the scope and prospects for the development of electric vehicles, hydrogen energy, energy storage and various distributed energy sources in China.

As a global frontrunner in the green energy transformation, Denmark has many years of experience in energy planning, legislation, policy implementation and regulation, and clean energy technology development and deployment. The Climate Act requires Denmark to reduce CO_2 emissions by 70% by 2030 compared with the 1990 level and to be carbon neutral by 2050. Thanks to the emphasis on policies that accounted for environmental externalities and the large-scale deployment of offshore wind power in the early years, Denmark now has more than 50% of its electricity generation from wind and solar energy. A mature electricity market, a focus on energy security, increased system flexibility and electrification of the end-use sector make Denmark's renewable power an excellent opportunity for future growth. The Energy Island Project in the North Sea, as a landmark project with worldwide impact, provides the basis for further decarbonisation of the Danish power sector, sector coupling and large-scale interconnection of the power system across countries. Denmark is also among the global leaders in energy efficiency and has one of the highest penetration rates of district heating. Energy storage and heat pumps are vital to the future of thermoelectric coupling in the Danish building sector. Denmark is accelerating the transformation and application of new energy technologies, and its strong advocacy of P2X will promote deep decarbonisation in the transportation and industrial sectors in the future. Furthermore, the development of the CCUS technology will provide an effective guarantee for achieving its carbon neutrality target.

The low- and zero-emission energy transformation built to ensure stable economic and social development and people's livelihoods is the key to achieving climate goals and driving a comprehensive green and low-carbon transition of the economy and society. However, the changes in the global energy landscape in recent years and the energy transformation practices of various countries have made us acutely aware that energy supply chain stability and energy system resilience are essential issues that cannot be ignored in energy system transformation.

By drawing on the successful experiences of China and Denmark in green transformation, the "China Energy Transformation Programme" seeks to comprehensively explore the new opportunities and challenges brought by current changes in the world to the prospect and path of energy transformation, identify and analyse the inadequacies and gaps in the energy transformation, and propose some countermeasures for optimizing China's energy transformation path.

I want to thank the Energy Research Institute (ERI) team for their efforts, international partners such as the Danish Energy Agency (DEA), Columbia University Center on Global Energy Policy (CGEP), and the Norwegian Agency for Development Cooperation (NORAD) for their strong support and input to the research, and not least, our long-time cooperation partner, Children's Investment Fund Foundation (CIFF), for their support of the China Energy Transformation Programme and the preparation of this COP27 Special Report.

The China Energy Transformation Outlook 2023 report will be available early next year.

Wang Zhongying

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Key findings

- The global climate change situation is becoming increasingly severe, and CO_2 emissions continue to increase. The deep restructuring of the world energy supply and demand map, the complex international environment and the marked increase in instability and uncertainty in the energy market have added to the difficulty of the global energy transition. Nevertheless, the global consensus to move towards carbon neutrality is growing amidst the uncertain situation. New topics, such as the resilience of energy systems, have sparked the attention of governments and industries worldwide.
- China is steadfastly promoting energy transition as the world's largest developing country and largest energy consumer. China has increased its efforts to develop clean energy, and renewable energy has entered a phase of high proportion and large-scale development. Coal power plants are gradually becoming more efficient with less air pollution and play an essential role in ensuring energy security in China in its current setup. Meanwhile, China has paid particular attention to enhancing its energy system's regulation and reserve capacity, and the construction of a modern energy system is accelerating. Regarding energy consumption, China's energy efficiency has continued to improve, low-carbon technology innovation has accelerated, and green lifestyles are developing faster. Key regions such as the Yangtze River Economic Belt, the Guangdong-Hong Kong-Macao Greater Bay Area, the Yangtze River Delta, and the Yellow River Basin promote green and low-carbon development and energy transformation combining local realities, forming a new regional map of promoting the energy transformation in China.
- Denmark is internationally recognised as a leading pioneer in energy transformation and climate change mitigation. Through consistent efforts such as developing legislation, implementing policies, conducting pilot projects and demonstrating technologies, Denmark has built a world-class green energy system, which provides improvements to everyday life and greener, more affordable energy while ensuring the security of supply. Thereby, Denmark has achieved significant CO_2 reductions, solid economic growth and increasing energy efficiency throughout the past four decades through setting ambitious climate targets, large-scale deployment of wind power (both offshore and onshore), promoting electrification of the end-use sectors, adopting green heating based on district heating and heat pumps, together with the prospective development of green fuels from electricity (Power-to-X) and CCUS technologies,
- Both China and Denmark have ambitious goals for reducing CO_2 emissions from the energy sector, and both have long-term visions for the future carbon-neutral energy system. Even though the two countries have very different characteristics, many energy transformation elements are the same. Energy efficiency improvement on the demand side is needed to ensure that the pace of supply-side deployments can keep up and sustain the required economic growth. Green energy supply – technological progress and cost reduction make RE able to provide clean energy in bulk, mainly through renewable electricity, and green heating will replace fossil-fuel heating. Electrification will support the phase-down of fossil fuels in industry, transport and building sectors, in conjunction with the decarbonisation of the electricity supply. Hydrogen becomes a vital energy carrier based on sufficient and economical green electricity for hydrogen production, and it provides green energy for end sectors that have difficulty reducing emissions. Green hydrogen, combined with captured carbon, allows for the production of fuels for difficult-to-abate sectors such as heavy transport, shipping, and aviation. Sequestration of CO_2 creates the backstop or last resort option, which enables negative emissions by storing CO_2 in carbon sinks. Negative emissions can compensate for a modest level of emissions still in the system to ensure carbon neutrality. Finally, drivers for transformational change are needed,

including long-term planning, concrete innovation and implementation strategies and cooperation across stakeholders, nationally and internationally.

- The energy transition must be a global action. China's energy transition affects domestic green and low-carbon development and profoundly impacts global climate goals. Achieving net-zero emissions globally is a critical and daunting goal that requires close collaboration between countries worldwide.
- Integrating international experiences, the China Energy Transformation Outlook 2023, to be released in spring 2023, is one good example of international cooperation. It will provide insights into the development required for China's energy sector to achieve net-zero carbon emissions in the future. The report sets out three development scenarios intending to provide more detailed and quantitative analysis, as well as more in-depth thinking, for China to understand the timeline and roadmap for its future energy transformation and to deal with the relationship between energy transformation and energy security in an integrated manner, through the analysis and comparison of different scenarios.

Chapter 1

New Situation and New Challenges Faced by The Global Community in Addressing Climate Change and Energy Transformation

1 New Situation and New Challenges Faced by The Global Community in Addressing Climate Change and Energy Transformation

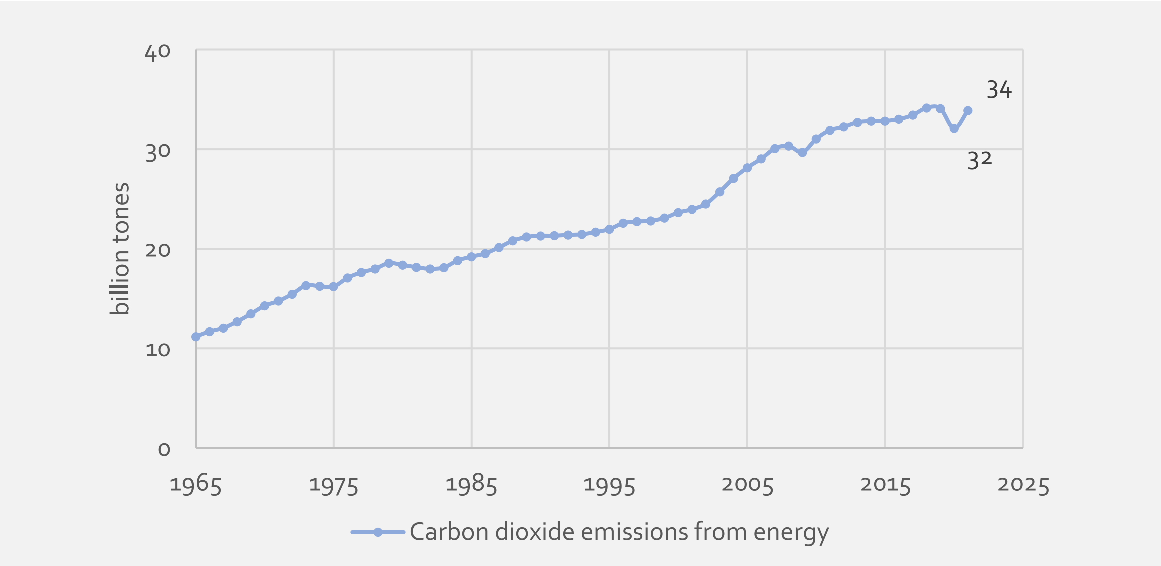
The past two years saw increasing deterioration of the global climate change situation, with heat waves, droughts, water shortages, extreme cold weather and other extreme climatic phenomena occurring frequently, echoed by significant fluctuations in the global energy market because of the COVID-19 pandemic, the Ukraine crisis, and the geopolitical situation. Energy security and economic sustainability has become a global focus. Energy transition is facing both short-term difficulties and long-term challenges, as complex and systematic issues associated with the transformation emerge.

Despite these challenges, the global consensus on the need for action on climate change has not changed, and concerns about energy security and energy prices may further drive the green energy transition on a global scale. This chapter provides a brief overview of the global situation, presenting a background and framework for subsequent detailed discussions on the development of green energy transitions in China and Denmark.

1.1 The deteriorating global climate change situation coincides with increasing fluctuations in CO2 emissions

In the past two years, effects of global climate change have been more and more pronounced, as evidenced by the frequency of severe weather events. According to the World Meteorological Organization (WMO) State of the Global Climate 2021 report, the period from 2015 to 2021 was the hottest years on record. In 2021, global average temperature was about 1.11°C higher than the world's average between 1850 and 1900 (the "pre-industrial average"). 2021 was also one of the top 10 warmest years on record globally. In western North America and the Mediterranean, people experienced record-breaking "abnormal heat waves," with Death Valley, California, recording a temperature of 54.4°C on July 9, 2021, the world's highest since the 1930s. Mid-July 2021 saw the worst flooding on record in Western Europe, where Western Germany and Eastern Belgium were the most severely affected. In July 2021, Lake Mead, a reservoir located on the Colorado River in the southwestern United States, saw its waterline fall 47 meters below the level if it were fully filled. This marked the lowest level on record. This summer, China's middle and lower reaches of the Yangtze River were hit by a severe drought not seen in decades and persistent high temperatures, causing severe water shortages in this region, where hundreds of millions of people are living. Global climate change is having a more and more pronounced influence on human production and life. It is in this context that the WMO calls on countries to step up efforts to address climate change and protect our home planet.

Figure 1 Global energy-related CO2 emissions



Source: BP Statistical Review of World Energy - 2022

Despite this, global CO2 emissions continue to grow amid fluctuations. According to data published in BP Statistical Review of World Energy, in 2020, global energy-related CO2 emissions decreased by 5.9%, compared to the 2019 level, but rose again by 5.6% to 33.9 billion tons in 2021. Albeit the fact that most countries around the world have proposed their own carbon neutrality targets, the reality of global carbon emissions reveals that it is still a far cry from the goal to limit the global average temperature rise to well below 2°C, and to aim for 1.5°C. The IPCC Sixth Assessment Report states that according to the Nationally Determined Contributions (NDCs) currently submitted by countries, global temperature rise could reach 2.8°C by the end of this century. To achieve the 1.5°C temperature rise control target, global greenhouse gas (GHG) emissions need to peak by 2025, decline by about 43% from peak levels in 2030, and achieve net zero CO2 emissions by 2050. To realize these goals, countries need to accelerate their energy transition and take more vigorous measures to jointly address climate change.

Box 1 The IPCC releases the Working Group III (WGIII) report to the Sixth Assessment Report (AR6)

On April 4, 2022, the Intergovernmental Panel on Climate Change (IPCC) released the Working Group III (WGIII) report to the Sixth Assessment Report (AR6), Climate Change 2022: Mitigation of Climate Change. The report summarizes the progress made by the international scientific community in the field of climate change mitigation since the release of the Fifth Assessment Report (AR5), describes the status of global greenhouse gas emissions, emission reduction pathways to limit global warming to different levels, and synergies between climate change mitigation and adaptation actions and sustainable development, and reveals the importance and urgency of implementing profound industry-wide GHG emission reduction, especially for energy systems, in order to achieve different levels of temperature rise control. Meanwhile, it also underscores the need for undertaking the climate change mitigation actions in the context of sustainable development, equity and poverty eradication, in order to make them more acceptable, sustainable and effective.

The report notes that limiting global warming will require major transitions in the energy sector. This will involve a substantial reduction in fossil fuel use, widespread electrification, improved energy efficiency, and use of alternative fuels (such as hydrogen).

“We see examples of zero energy or zero-carbon buildings in almost all climates,” said IPCC Working Group III Co-Chair Jim Skea. “Action in this decade is critical to capture the mitigation potential of buildings.”

Reducing emissions in industry will involve using materials more efficiently, reusing and recycling products and minimising waste. For basic materials, including steel, building materials and chemicals, low- to zero-greenhouse gas production processes are at their pilot to near-commercial stage.

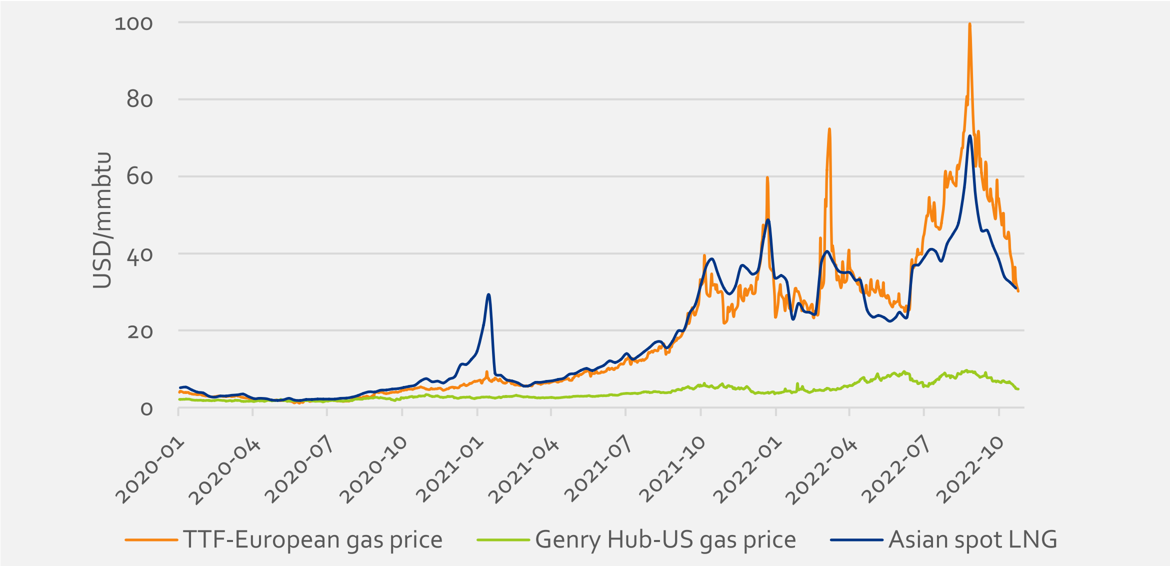
The industry sector accounts for about a quarter of global emissions. Achieving net zero will be challenging and will require new production processes, low- and zero-emissions electricity, hydrogen, and, where necessary, carbon capture and storage.

Agriculture, forestry, and other land use can provide large-scale emissions reductions and also remove and store carbon dioxide at scale. However, land cannot compensate for delayed emissions reductions in other sectors. Response options can benefit biodiversity, help us adapt to climate change, and secure livelihoods, food and water, and wood supplies.

1.2 Geopolitics aggravates the imbalance between energy supply and demand, which adds to the challenges already facing the energy transition.

The COVID-19 pandemic of the last two years has posed unprecedented challenges to global development, which, coupled with effects of the Ukraine crisis and inflation, intensifies the turbulence in global energy markets. Starting the second half of 2021, global energy prices have risen sharply, with international oil prices once approaching $140/barrel and natural gas prices in Europe, North America and Asia hiking by 90%-400%, respectively. As many European countries are trapped in an energy crisis, there is a possibility that energy shortage and price hike will spread globally. The World Bank has forecast energy prices to rise by 50% or greater in 2022, and to stay at historically high levels until 2024. Over the past two years, Europe has also experienced severe oil and gas supply shortages. As an emergency security measure and strategic reserve, many European countries have to increase coal consumption in the power sector. In addition to Europe, fluctuations in energy market supply and demand and high energy prices are posing serious challenges to the economy and livelihoods of many countries and are set to adversely affect energy prices and stable energy supply in East Asia.

Figure 2 Changes in natural gas prices in the U.S., Europe and Asia



Source: Refinitiv

The increased volatility in energy markets is the combined result of multiple factors. In the short-term, such factors as the evolving and recurring COVID-19 pandemic, the unresolved and unpredictable Ukraine crisis, and uncertainties associated with global economic outlook and energy demand recovery, are at work. In the medium term, affected by a combination of factors, such as low-carbon transition and rising investment and financing costs in recent years, global investment in oil and gas upstream in 2016-2020 was only US$392 billion, down 37% from the 2010-2015 level. Lack of investment inclination in upstream oil and gas extraction projects has caused a significant gap in fossil energy supply capacity, which became a focal issue in the last two years. In the long term, the world needs to withdraw from fossil energy and develop a carbon-neutral energy system. The combined effects of both internal and external factors result in increased volatility in global energy markets. In light of the increasingly complex situation, any failure on our part to respond properly to the frequent shocks created by these complex factors are bound to cause negative effects on the global energy transition.

1.3 The consensus on carbon neutrality is strengthened in the new turbulence, and energy system resilience becomes the newest buzzword.

Despite increased energy market turbulence especially in the past two years, most developed countries still consider accelerating new energy development and early realization of energy transition as a pivotal way to ensure energy security and to effectively respond to global climate change. The consensus on striving for carbon neutrality has, in this sense, been further strengthened. The EU forecasts its installed wind and solar PV capacity to double by 2025 and to triple the current level to 480 GW of new wind turbine installations and 420 GW of new solar PV installations by 2030, when they are to replace 170 billion m3 of natural gas demand. Meanwhile, the EU also plans to produce 35 billion m^3 of biomass gas and to replace 25 - 50 billion m^3 of natural gas with hydrogen by 2030. Germany has advanced its target year for carbon neutrality from the previous 2050 to 2045, while also requiring to have all the needed laws, regulations and supporting measures in place by the end of 2022 to ensure a full transition. Furthermore, the new German government is considering advancing the phase-out of coal from 2038 to 2030, and increasing the share of renewable electricity to 80% of all power generation by 2030, in an effort to achieve energy independence and carbon neutrality as soon as possible.

Over the past several years, energy system resilience has become a hot topic of discussion in the global energy community. On the one hand, to enhance energy system resilience is of relevance to reflect the inherent characteristics of the stochastic, intermittent and volatile nature of renewable energy. Traditionally, the centralized energy supply mode characterized by "large capacity, high parameter and long distance" has a strong control over energy flows and does not require additional resilience services from the energy system. With renewable energy taking up an increasing share in the energy system worldwide, the improvement of energy storage, peak capacity and demand side flexibility in the power and heating systems, and the enhancement of the resilience of energy systems has become an inevitable choice for steadily promoting energy transition. On the other hand, with the increasing number of emergencies having greater impacts on the fossil energy industry and supply chain, enhancing the reserve capacity and energy system resilience has also become a top priority to ensure national energy security and the normal operation of economy and society. As the global situation intensifies its impact on the energy industry and supply chain, the matter of energy system resilience has drawn the attention of more and more countries around the world.

Chapter 2

China's Steady Efforts to Advance Energy Transition Provides Strong Support for Carbon Peak and Neutrality Goals

2 China's Steady Efforts to Advance Energy Transition Provides Strong Support for Carbon Peak and Neutrality Goals

China experienced a fast economic recovery in 2020 and 2021 as the world combatted the COVID-19 pandemic. Despite being impacted by international geopolitical changes, global energy market turbulence, and domestic industry and energy mix adjustment, China's energy and electricity demands rebounded rapidly. Regardless of the regional, time-specific, and standalone supply, shortage associated with certain energy types, energy security has in general been fully ensured, and energy transition is advancing steadily.

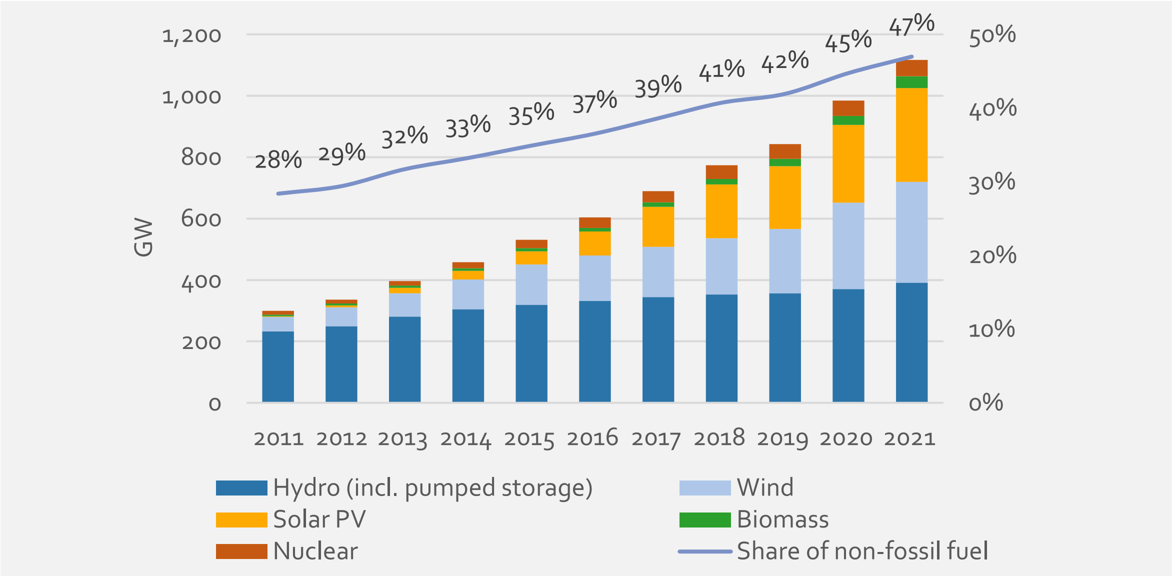
2.1 Intensified efforts in clean energy development help create a new pattern of energy development

Guided by the new development concept of innovation, synergy, green-ness, openness and sharing, China has intensified efforts to develop non-fossil energy, continuously consolidate the country's industrial advantages, and strive for rapid development of non-fossil energy. According to data released by the National Bureau of Statistics, in 2021, the share of clean energy (comprising non-fossil energy and natural gas) in China's primary energy consumption reached 25.5%, an increase of 1.2 percentage points year-on-year, of which non-fossil energy accounted for about 16.5% of primary energy consumption, an increase of 0.6 percentage points year-on-year. In 2021, non-fossil energy consumption was about 870 Mtce, an increase of 9.3 percentage points year-on-year, of which renewable energy electricity is equivalent to 748 Mtce, an increase of 11 percentage points year-on-year, accounting for 14.3% of the primary energy consumption, an increase of 0.8 percentage points year-on-year; nuclear power contributes 116 Mtce, accounting for 2.2% of primary energy consumption, an increase of 0.1 percentage points year-on-year.

With the advance of large-scale wind and solar PV development, China has made a good start and new breakthroughs in the field of non-fossil energy for the 14th Five-Year Plan period until 2025. It reveals two new characteristics:

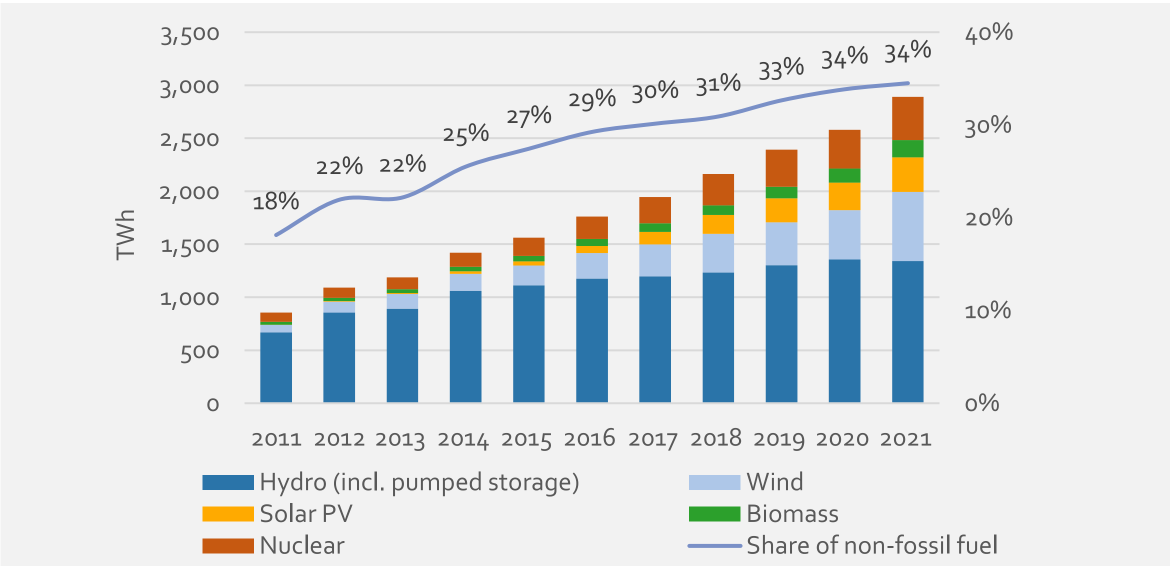
Firstly, for the first time in history, non-fossil energy capacity exceeded coal power, and the installed capacity of renewable energy exceeded 1 billion kilowatts. In 2021, additional 137 GW of non-fossil energy were installed, accounting for 78.0% of the country's newly installed capacity. Newly installed renewable energy capacity was 134 GW, accounting for 76.1% of the country's newly installed capacity. As of the end of 2021, China's cumulative non-fossil energy capacity reached 1120 GW, exceeding coal power capacity for the first time in history, accounting for 47% of the country's total installed capacity, up 2.3 percentage points from the previous year. The cumulative installed renewable energy capacity reached 1063 GW, accounting for 44.8% of the country's total installed capacity. Nationwide, non-fossil energy generation reached 2890 TWh, up 12% year-on-year, accounting for 34.5% of all power generation. Renewable energy generation amounted to 2480 TWh, accounting for 29.7% of all power generation.

Figure 3 Installed capacity and proportion of renewable energy power by type



Source: National Energy Administration (NEA)

Figure 4 Electricity generation and proportion of non-fossil fuel generation



Source: NEA

Secondly, the installed capacity of wind and solar PV power generation both exceeded 300 GW, and wind power's share in total power generation exceeded 10% for the first time in history. Wind power development maintains a rapid growth, with central-eastern and southern regions seeing their newly installed capacity taking up a 60% share or greater of total installations. Offshore wind power grows particularly fast. The newly installed offshore wind power capacity reached 16.9 GW in 2021, representing a significant increase of 4.5 times the previous year, making the cumulative grid-connected power reach 26.4 GW. Newly installed solar PV power capacity hit a new record high. Newly installed distributed PV capacity increased by 89% year-on-year to 29.3 GW, exceeding newly installed capacity of centralized PV power plants for the first time in history. The cumulative installed distributed PV capacity exceeded the 100 GW mark and amounted to 306 GW cumulatively. Nationwide, wind and solar PV power generation accounted for 7.8% and 3.9%, respectively, of the total power generation in 2021. For the first time in history, wind and solar PV power generation combined constituted more than a 10% share of China's total power generation.

Thirdly, clean replacement of fuels in the end use sectors has accelerated. In the northern region, the clean heating target has been met ahead of schedule, following the completion of a total of 15.6 billion m^2 in clean heating area, at a clean heating rate of 73.6%. Cumulatively, consumption of more than 150 million tons of loose coal were replaced, which contributes to more than 1/3 of the reduction in PM2.5 concentration and improvement in air quality. The development of electric vehicle charging facilities has also accelerated, with a total of 3.92 million charging piles having been built as of June 2022 to form the world's largest charging infrastructure capable of meeting the charging needs of more than 20 million electric vehicles by 2025.

Box 2 China power market reform speeded up

China's power market reform has gathered pace in recent years. In 2015, China launched a new round of power sector reforms. It was marked by the release of several opinions from the CPC Central Committee and the State Council on Further Deepening the Reform of the Electric Power System. The most fundamental and significant content of the reform is the goal of establishing a "fair, normative, efficient, competitive, open-access, and non-discriminative" electricity wholesale market to trade electricity through a market-based mechanism. It also includes key areas such as establishing relatively independent power exchanges, improving overall planning of power system development and government regulation, and so on. The deepening reform draws on experiences from the electricity market development in some countries, aiming to transform electricity pricing towards market-based pricing.

The power market reform gathered further pace in October 2021 following the power shortages during the intersecting seasons of summer and autumn. The National Development and Reform Commission (NDRC) announced reforms to the coal-fired power tariff (Document No.1439) and expanded the coverage of power trading. This was seen as a key milestone in China's power market reform and signalled a further acceleration in the process. Document No.1439 stipulates that coal power must be market-oriented through the electricity market and widened the coal-fired benchmark tariff fluctuation band from +10% & –15% previously to ±20%. This enabled further pass-through of coal prices to the tariff and partly offset the pressure on coal plants' losses. All coal-fired generation, as well as all industrial and commercial users, to purchase electricity from the market, either directly or via grid companies. This vastly expands the coverage of power trading. In 2022, it is expected that more than 70% of China's overall power generation will be covered by market-based transactions, up from 45% in 2021.

The reform gathered yet further pace in November 2021 with the "Guidance on Establishing National Unified Electricity Market System". The Guidance sets a clear roadmap for China's power sector reform, aiming to establish a multilayer power market system, consisting of mid- to long-term, spot and ancillary services markets and gradually integrating the provincial and regional power markets into a national market, encouraging the market-oriented allocation of cross-provincial and cross-regional power resources and significantly increasing green power trading. This process will take place in two phases, with the establishment of the system by 2025 and completion by 2030.

In the meantime, the regulators are proceeding with expansion of the spot-trading pilots. In 2022, the first batch of eight spot-trading pilot provinces entered continuous trading and the second batch of six spot-trading pilots started trial by June. The deepening and further rollout of the spot-trading pilots will continue in the coming years. In the meantime, medium- to long-term trading will remain the main trading type until at least 2025, with spot markets being fully developed by 2030. Further progress in the power market reform will facilitate more effective utilisation of generation resources and grids, the establishment of the decarbonised power system and incentivise the deployment of clean energy.

2.2 Green and low-carbon transformation of coal and coal power helps safeguard national security, uphold economic stability and benefits people's livelihoods

In 2021, China's total installed power generation capacity increased to 2380 GW, among which the installed coal power generation capacity was 1110 GW, accounting for 46.7% of the total installed power generation capacity[1] . Around 1.03 billion kilowatts of coal-fired units, accounting for about 93.0% of the country's total installed coal power capacity, meet ultra-low emission limits for pollutants[2] . In 2021, the standard coal consumption of thermal power plants nationwide with a generation capacity of 6,000 kilowatts and above was 301.5 g/kWh, 2.01 g/kWh lower than the previous year's level; the electricity consumption rate of thermal power plants nationwide with a generation capacity of 6,000 kilowatts and above was 4.36%, 0.29 percentage point lower than the previous year's level, indicating a steady efficiency improvement of coal power generation. In 2021, CO2 emissions per unit of thermal power generation nationwide were around 828 g/kWh, 21.0% lower than the 2005 level. In recent years, coal power generation as a share of total electricity production has been steadily declining and fell to 60% in 2021. Due to the rapidly increasing demand for electricity, the pace of new renewable power generating was not sufficient to meet the new electricity demand. In order to keep normal economic operations, coal power generation increased by 8.9% and gas power generation by 13.7% in 2021. At a critical moment in tackling power shortages, coal and gas power played an effective role as a ballast for ensuring power security.

In terms of coal consumption structure, whilst the coal consumption of non-power sectors declines, that of the power sector is rising, thus contributing to pollution reduction and carbon reduction, and a cleaner and more efficient use of coal overall. According to the statistics of China Coal Industry Association (CCIA), China's coal consumption in 2021 was 4.27 billion tons, of which 3.95 billion tons were consumed by four industries: electricity, iron and steel, chemical and building materials, which account for 93%[3] of the country's total coal consumption combined. Meanwhile, decentralized use of "scattered coal" by small boilers and kilns is shrinking as a share of total coal consumption. Of the country's newly added coal consumption in 2021, coal for use in power generation accounted for more than 90%, suggesting an increasing coal share in the power generation industry and a cleaner and more efficient coal consumption pattern. China is committed to promoting the gradual transformation of coal into clean fuels, superior raw materials and high-quality materials. According to preliminary estimates, the annual conversion of coal used as raw materials and materials in China's industrial sector exceeds 100 Mtce.

Box 3 China launched the national ETS in 2021

China's newly established national emissions trading system (ETS) is expected to serve as the primary tool in assisting China to meet its "dual carbon" target of peaking CO_2 emisisons before 2030 and achieving carbon neutrality before 2060.

In 2021, China launched the national ETS after a decade in the making, built upon experiences from pilot schemes. The national ETS covers more than 2,000 enterprises in the power sector and annual emissions close to 4.5 billion tonnes of CO_2 per year, or around 40% of China's total. Unlike similar schemes elsewhere, such as in the European Union, China's allocation of emissions allowances is not decided upfront via an absolute cap but is based instead on benchmarks of emissions intensity (tCO_2/MWh), considering growing energy demand and consistency with intensity-based energy and CO_2 targets at the national level. One allowance means a company can emit 1 tonne of carbon dioxide. Enterprises whose thermal power plants' emissions intensity is above the benchmark will need to purchase allowances from those plants that are more efficient and below the benchmark intensity. In addition, companies can cover up to 5% of their compliance obligation with China Certified Emissions Reductions (CCER), which are credits issued from government-certified domestic emissions reduction projects. Example activities include renewable power generation, forestry projects, and waste-to-energy projects.

In terms of trading, the national ETS's performance in the first year was limited. The price of the China Emission Allowance (CEA) has been relatively low at between RMB 40 and RMB 60 since it launched trading on July 16, 2021, averaging RMB 43.85 (€6)/t in 2021's 114 trading sessions. A total of 179 million tonnes were purchased. This price level is a fraction of the price in more mature ETSs, such as the €80/t in the EU's ETS. Thus, it currently only has limited impact in terms of driving emissions reduction. In addition, the dominance of over-the-counter trading and low trading volumes of most of the sessions indicate that the level of liquidity still has some room to improve. Daily trading volumes stayed low at several hundred thousand tonnes but surged to a million tonnes per day in December just before the year-end compliance deadline.

On December 31, 2021, the Ministry of Ecology and Environment officially announced that the first compliance period had been successfully completed. The compliance rate was 99.5% based on covered emissions. This means that the majority of the 2,162 power sector enterprises in the scheme surrendered allowances before the deadline, meeting their compliance obligation for the 2019–2020 period.

China's national ETS will undergo continuous improvement with the policy framework becoming stronger and more complete, allowance allocation rules becoming stricter, and trading liquidity increasing further. The next compliance period will cover both 2021 and 2022. It will then impact generation decisions in contrast to back-dated coverage in the first compliance period. Sector expansion and the introduction of more trading participant types and carbon derivatives will take place later. Meanwhile, the eight existing provincial pilot ETSs will gradually integrate with the national ETS. Going forward, the national ETS is expected to cover all industrial sectors, eventually over 70% of China's total national emissions. As stated in the 2022 Report on the Work of the Government, delivered March 2022, the national assessment of the total amount and intensity of energy consumption will transition to the assessment of the total amount and intensity of carbon emissions. The ETS and broader carbon pricing mechanism will make enterprises more aware of carbon costs and more focused on reducing emissions and will help China achieve its carbon peak and neutrality pledge through the ETS cap and associated climate finance mechanisms.

2.3 With enhanced regulation and reserve capacity, the development of a modern energy system is accelerated

China's new energy storage has gradually evolved from R&D demonstration to early-stage commercialised development, with its market application scale steadily expanding. In 2021, the installed capacity of China's new energy storage exceeded 4 GW. Significant progress has been made on the front of new energy storage technology, as evidenced by improved efficiency, reduced cost, extended life span and enhanced safety. Energy storage has begun to demonstrate its supporting role for the energy transformation. New energy storage application scenarios and business models continue to expand, and diversified application scenarios, such as new energy plus energy storage, base power supply equipped with energy storage, "internet and energy storage", and "distributed smart grid and energy storage", are emerging one after another. The policy system and market mechanisms for new energy storage are initially taking shape. A batch of new favourable mechanisms and policies for innovation planning, application project management, and power market and dispatching operation participation, are being developed and implemented.

On March 22, 2022, the Chinese government released the "14th Five-Year Plan for Modern Energy System Development", specifying the need to promote the development of a modern energy system from three aspects:

First, to enhance energy supply chain security and stability. Starting from the 14th Five-Year Plan period, China will strengthen its comprehensive energy security capacity in three dimensions: strategic security, operational security and emergency security, and is expected to have a comprehensive energy production capacity of over 4600 Mtce by 2025 to meet its economic and social development and to ensure people's livelihood.

Second, to promote green and low-carbon transformation of energy production and consumption. The 14th Five-Year Plan period is a crucial period and a window of opportunity for China to achieve carbon peaking. China will focus on the "addition" of increasing the supply capacity of clean energy and the "subtraction" of reducing carbon emissions in the energy industry chain, in a bid to promote the formation of green and low-carbon energy consumption patterns, and to increase the proportion of non-fossil energy consumption to about 20% by 2025

Third, to enhance the modernisation level of the energy industry chain. During the "14th Five-Year Plan" period, China will continue to take advantage of science and technological innovation as the biggest driving force for energy development, enhance the capacity of energy science and technology innovation, accelerate the digitalisation and intelligent upgrading of the energy industry, enable a significant increase in energy system efficiency, and comprehensively improve the level of advanced energy industry foundation and industry chain modernisation.

2.4 While energy utilisation efficiency continues to improve, low-carbon technology innovation is advancing at an accelerated pace

In 2021, Chinas total energy consumption was about 5240 Mtce, an increase of 5.2% over the previous year. In 2021, Chinas energy consumption per unit of GDP declined by 2.7% compared with the 2020 level, representing an increase of 2.6 percentage points over the previous year in terms of the rate of decline. In 2021, Chinas energy consumption per unit of added value in industries above designated scale decreased by 5.6% compared with the previous year's level; the comprehensive energy consumption per unit of calcium carbide in key energy-consuming industrial enterprises decreased by 5.3%; the comprehensive energy consumption per unit of synthesis ammonia remained the same as the previous year; the comprehensive energy consumption per ton of steel decreased by 0.4%; the comprehensive energy consumption per unit of electrolytic aluminium decreased by 2.1%; and the standard coal consumption per kilowatt-hour of thermal power generation declined by 0.5%[4], all suggesting steady improvements in energy efficiency.

Progress has been made in low-carbon development initiatives in the building and transportation sectors. In the building sector, as of the end of 2021, China completed a total of over 8.5 billion m^2 of green building area; the proportion of new green buildings in urban areas nationwide was 84% of the new building area of the same year, with a total of nearly 10 million m^2 of ultra-low energy and near-zero energy building area completed. In the transportation sector, China sold more than 3.5 million new energy vehicles and had a vehicle stock of 7.84 million in 2021, both of which ranked first in the world. As of June 2022, China's new energy vehicle fleet reached 10.1 million, exceeding the 10 million mark for the first time in history, of which 8.1 million were pure electric vehicles (PEVs), accounting for 80.9% of total new energy vehicles. As of the end of 2020, China's new energy bus stock reached 466,100, accounting for 66.2% of all buses. Gasoline and diesel vehicles are being replaced by new energy vehicles in the urban public transport system.

Box 4 Progress in China's Carbon Peak and Carbon Neutrality Policies

Under the unified deployment of the CPC Central Committee and the State Council, and through the organisation and implementation of the Carbon Peak and Carbon Neutrality Leading Group, China has been steadily and earnestly pushing forward the work surrounding the "dual carbon" goals.

1) Creating an overall planning and coordination mechanism. A Carbon Peak and Carbon Neutrality Leading Group was set up at the central level. The National Development and Reform Commission (NDRC) assumes the role of the Leading Group Office and undertakes the responsibility of strengthening organizational leadership and coordination, creating a work system to facilitate interactions between superior and subordinate levels and strengthening collaboration among all involved parties.
2) Building a "1 + N" policy system. The Party Central Committee and the State Council jointly issued a document titled "Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy"; the State Council issued the "Action Plan for Carbon Dioxide Peaking before 2030"; all relevant departments formulated and issued their respective implementation plans and support policies in various fields and industries; and all provinces (autonomous regions and municipalities) also formulated individual implementation plans for carbon dioxide peaking in their own regions. With all these efforts, a "1+N" policy system has been put in place.
3) Promoting green and low-carbon energy transformation in a steady and orderly manner. In light of China's "coal-dominated" basic national condition, it is imperative that vigorous efforts be made to promote the clean and efficient use of coal, to promote pollution reduction and carbon reduction to carry out the so-called "san gai lian dong" plans (concurrent energy-saving, carbon-reduction transformation, heating transformation, and flexibility transformation of coal-fired power units), and to plan and develop a total of 450 million kilowatts of large-scale wind power and solar PV power generation bases in desert and Gobi regions. Currently, China's installed renewable energy capacity exceeds 1100 GW, ranking first in the world.

4) Vigorously promoting the optimisation and upgrading of industrial structure. Active efforts should be made to develop strategic emerging industries, with a special emphasis placed on promoting energy-saving and carbon-reducing transformation of key industries and strictly avoiding pell-mell development of energy-intensive, high-emission and low-level projects. Compared with the 2012 levels, China's energy consumption intensity fell by 26.4% by 2021; carbon emission intensity fell by 34.4%; water consumption intensity fell by 45%; and the output rate of major resources increased by 58%.
5) Promoting the low-carbon transformation of the building, transportation sectors. Active efforts should be made to develop green buildings and promote green and low-carbon renovation of existing buildings. In 2021, new green building area in cities and towns nationwide was over 2 billion m^2. It is also important to step up the popularisation of energy-saving and low-carbon transportation means. China's new energy vehicle production and sales have ranked first globally for seven consecutive years, and China's vehicle holdings accounted for more than half of the world's total.
6) Consolidating and enhancing the carbon sequestration capacity of ecosystems. It is important that we continue to carry out integrated protection and restoration of mountains, waters, forests, lakes, grassland and deserts, and to advance large-scale national greening action in a scientific way; having maintained growth in both forest coverage rate and forest growing stock, China has become a global leader with the largest increase in forest resources.
7) Establishing and improving relevant policy mechanisms. It is important that we optimise and improve the dual control policy on energy consumption and energy intensity, create a unified and standardised carbon emission statistics and accounting system, roll out support tools for carbon emission reduction and special refinancing loans for clean and efficient use of coal, and launch a national carbon market. It is also important to improve the green technology innovation system, provide more training to "dual-carbon" professionals, further promote the green living creation action, advocate green lifestyles, and encourage green consumption.
8) Actively participating in global climate governance. It is important that we play an active and constructive role in multi-bilateral mechanisms; step up efforts to create a fair and reasonable global environmental governance system featuring win-win cooperation; deepen South-South cooperation in addressing climate change; solidly advance the construction of the green One Belt and Road; and support the green and low-carbon energy development of developing countries.

Chapter 3

Achievements and Trends of Energy Transition in Major Regions of China

3 Achievements and Trends of Energy Transition in Major Regions of China

Regions are important spaces for economic and social development and ecological protection, as well as key carriers for the production and supply and consumption, and circulation of energy. Since the 18th National Congress of the CPC, China has successively put forward the new energy security strategy of "Four Revolutions and One Cooperation", as well as major regional development strategies such as the coordinated development of Beijing-Tianjin-Hebei region, the integrated development of the Yangtze River Delta, the Yangtze River Economic Belt, the Guangdong-Hong Kong-Macao Greater Bay Area, and the ecological protection and high-quality development of the Yellow River Basin, which have made corresponding regional deployment and spatial guidelines for energy transition and green and low-carbon development and have witnessed a series of representative achievements and several landmark clean energy projects and facilities.

3.1 The Region of the Yangtze River Economic Belt

The Yangtze River Economic Belt is a river basin economic belt spanning three regions of the east, central, and west of China, with a geographical scope covering 11 provinces and cities from southeastern to southwestern of the country, including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Guizhou, and Yunnan, accounting for about 1/5 of the national territory, with a total population and economy of more than 40% of the country, and with the typical characteristics of important ecological status, strong comprehensive strength and huge development potential. In September 2016, the *Yangtze River Economic Belt Development Plan Outline* was issued, marking that the joint protection without large-scale development of the Yangtze River Basin has been formally elevated to a national strategy. July 2017, the *Yangtze River Economic Belt Ecological Protection Plan* puts forward phased targets, requiring optimisation of the energy structure and the control of total coal consumption of the Yangtze River Economic Zone, asking that by 2020, the total coal consumption should be controlled below 1.2 billion tce. With the strengthening of the Yangtze River Economic Belt strategy, the provinces and cities along the belt have gradually pioneered a road of ecological priority, green development and energy transformation.

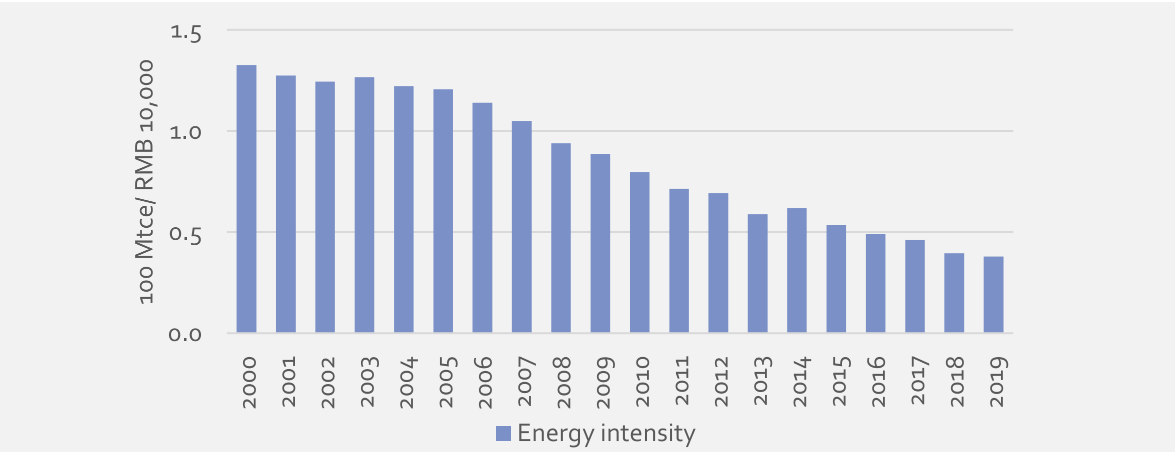
The policy system for the overall protection and development of the basin has been gradually improved

President Xi has inspected the development of the Yangtze River Economic Belt many times. In 2016, 2018, and 2020, he hosted symposiums in Chongqing in the upper reaches of the Yangtze River, Wuhan in the middle reaches, and Nanjing in the lower reaches of the Yangtze River and delivered important speeches, clarified the direction and laid down rules for the green and low-carbon development of the Yangtze River Economic Belt of "together with great protection, but not with great exploiting". During the 14th Five-Year Plan period, the Office of the Leading Group of the Yangtze River Economic Belt organized and compiled the *14th Five-Year Plan for the Development of the Yangtze River Economic Belt* and special plans and implementation plans for key areas and key industries, forming a "1+N" planning policy system for the development of the Yangtze River Economic Belt during the 14th Five-Year Plan, led by the "14th Five-Year Plan for the Development of the Yangtze River Economic Belt" and supported by a series of special implementation plans such as the comprehensive transportation system planning and environmental pollution control "4+1" project, wetland protection, plastic pollution control, protection and restoration of important tributary systems, etc.

The industrial transformation has been successful and the energy consumption intensity has continued to decline

Since the implementation of the Yangtze River Economic Belt strategy, the provinces and cities along the river have actively promoted industrial transformation, driving down the intensity of energy consumption. The data shows that from 2016 to 2020, more than 8,000 industrial enterprises along the Yangtze River Economic Belt have been relocated and transformed; the scale of industries such as electronic information and equipment manufacturing accounts for more than 50% of the national proportion, and the provinces and cities along the belt have a prominent position in the country in terms of basic research and key technology research, being in the lead in the digital economy, electronic information, biomedicine, aerospace and other industries of the country. On the whole, the average value of the three industrial structures of the 11 provinces and cities along the belt has been adjusted from 15.66, 46.54, 37.8 in 2000 to 7.23, 38.75, 54.02 in 2020. The proportion of the primary and secondary industries has dropped significantly, and the proportion of the tertiary industry has increased by 16.2%. Driven by the upgrading of the industrial structure, since 2000, the economic aggregate of the 11 provinces and cities along the Yangtze River Economic Belt has increased from 4.07 trillion yuan to 47.16 trillion yuan in 2020, an increase of about 11.6 times, and the nominal growth rate is as high as 13%. At the same time, the energy consumption intensity dropped from 1.33 tce/10,000 RMB in 2000 to 0.38 tce/10,000 RMB in 2019, which fully reflects the effectiveness of the green and low-carbon transformation and development path of the Yangtze River Economic Belt.

Figure 5 Changes in the energy consumption intensity of the Yangtze River Economic Belt from 2000 to 2019



The achievements of the construction of super hydropower stations have attracted worldwide attention

The Yangtze River Economic Belt relies on the Yangtze River, with the most prominent resource advantage being abundant hydropower resources. Thanks to this, several super hydropower stations constructed on its course gained world-renowned achievements. Among them, the hydropower station of the Three Gorges Dam was completed in 2009 with a total installed capacity of 22.5 GW. It is the largest hydropower station in the world and the largest engineering project ever built in China. Since its completion, China has successively built four super hydropower stations on the Yangtze River and its tributaries, namely Wudongde Hydropower Station (10.2 GW), Xiluodu Hydropower Station (13.86 GW), Xiangjiaba Hydropower Station (6.4 GW) and Baihe Hydropower Station Tan Hydropower Station (16 GW), whose installed capacity all ranks among the top in the world. They do not only provide a steady stream of clean electricity for the provinces and cities along the Yangtze River but also make positive contributions to the ecological environment on both sides of the river.

Box 5 Construction of super hydropower stations along the Yangtze River

Downstream the Yangtze River, there are five super hydropower stations including the Three Gorges Dam, Wudongde Dam, Baihetan Dam, Xiluodu Dam, and Xiangjiaba Dam. Among them, the Three Gorges Hydropower Station has a total installed capacity of 22.5 GW, which is the largest hydropower station in the world. Wudongde Hydropower Station has a unique design. The thickness of the bottom of the dam is 51 meters, while the thinnest part of the top is only 0.19 meters. Relying on the arched dam body and the new construction materials and techniques used to withstand the pressure of water flow, it is a seemingly thin building as well as a strong and durable dam. Baihetan Hydropower Station is the second largest hydropower station in China after the Three Gorges Dam, with a total installed capacity of 16 GW. As the second cascade hydropower station developed in the lower reaches of the mainstream of the Jinsha River, with an average annual power generation of 62.44 TWh, Baihetan can save 19.68 Mtce and reduce carbon dioxide emissions by 51.6 Mt every year. The two hydropower stations, Xiangjiaba and Xiluodu, which were built in 2014 and 2015, are reservoirs with mutual adjustment functions on the Jinsha River. Xiangjiaba Hydropower Station is also equipped with the world's largest ship lift.

Figure 6 Photos of five super hydropower stations along the Yangtze River

Three Gorges Dam

Wudongde Dam

Baihetan Dam

Xiluodu Dam

Xiangjiaba Dam

Source: Image from the web

3.2 The Region of Guangdong-Hong Kong-Macao Greater Bay Area

The geographical scope of the Guangdong-Hong Kong-Macao Greater Bay Area covers nine cities in Guangdong Province including Guangzhou, Shenzhen, Zhuhai, Foshan, Dongguan, Zhongshan, Huizhou, Jiangmen, Zhaoqing, and Hong Kong SAR and Macao SAR. With a total area of 56,500 square kilometers. In 2021, the total economic volume of the Guangdong-Hong Kong-Macao Greater Bay Area has reached 12.6 trillion yuan, creating about 11% of the country's total economic volume with less than 1% of the national territorial area; there are 24 Fortune 500 companies and 57,000 high-tech companies., being one of the world-class urban agglomerations with the largest economic volume and the most innovative vitality in the country.

In 2019, the Central Committee of the CPC and the State Council officially issued the *Development Plan of Guangdong-Hong Kong-Macao Greater Bay Area*, marking the entry of a new stage in the construction of the country's Greater Bay Area. With the deepening of the construction of the Guangdong-Hong Kong-Macao Greater Bay Area, the energy consumption structure in the region has been continuously optimized. In 2020, the total energy consumption of the Greater Bay Area was 264 Mtce. In terms of the growth rate of energy consumption, except for the growth rate of over 10% in 2010, the overall growth rate of energy consumption in the Guangdong-Hong Kong-Macao Greater Bay Area has shown a downward trend. From the perspective of energy consumption structure, in 2010, the comprehensive energy consumption structure of the Greater Bay Area was dominated by fossil energy, of which coal, oil, and natural gas accounted for 39.5%, 35.1%, and 5.7% of the total energy consumption, accounting for 80.3% of the total energy consumption, while electricity and other non-fossil energy accounted for only 19.7%. In 2020, the proportion of coal and oil consumption in the Guangdong-Hong Kong-Macao Greater Bay Area will both drop to 30.6%, the proportion of natural gas consumption increased to 12.6%, and the proportion of electricity and other non-fossil energy increased to 26.3%. Energy consumption continues to be cleaner.

Figure 7 Total energy consumption and growth rate of Guangdong-Hong Kong-Macao Greater Bay Area from 2010 to 2020

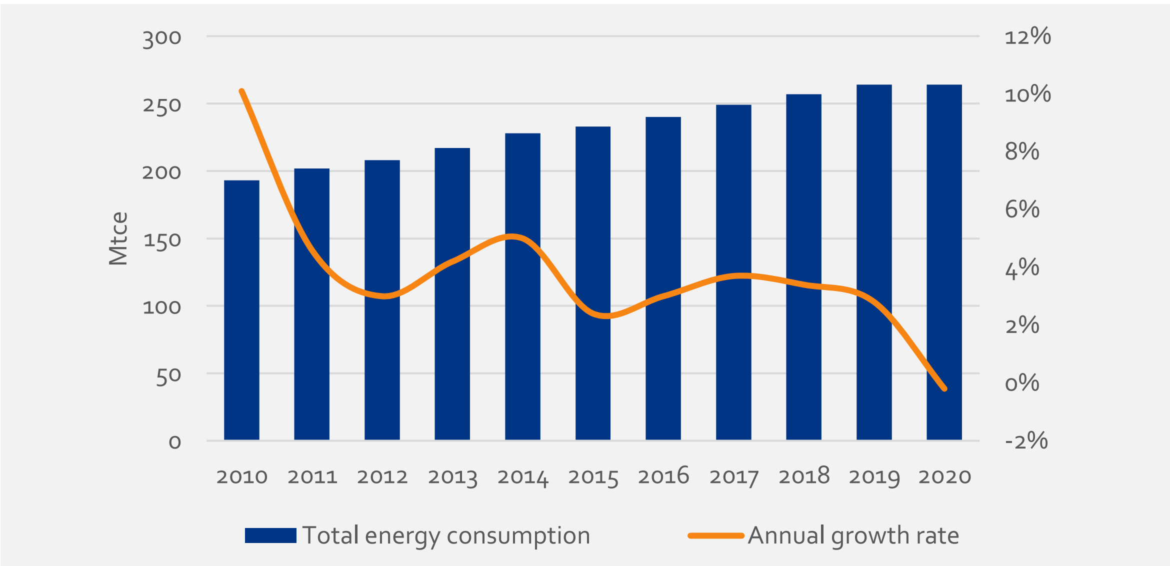
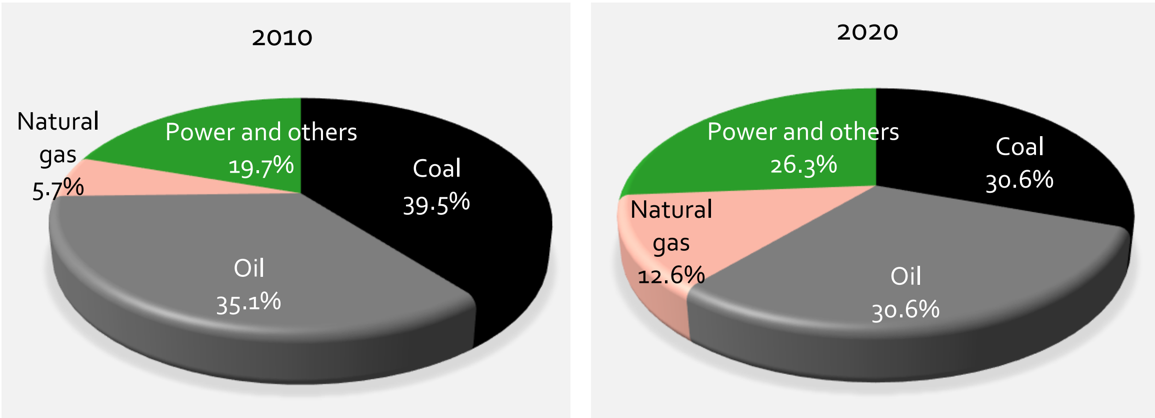


Figure 8 The energy consumption structure of the Guangdong-Hong Kong-Macao Greater Bay Area in 2010 and 2020



Take the lead in proposing carbon peaking at the city level

The energy consumption of the Guangdong-Hong Kong-Macao Greater Bay Area is concentrated in major cities, and it took the lead in proposing the goal of carbon peaking, ahead of China's overall goal. In 2020, the total energy consumption of nine cities in Guangdong Province was 244 Mtce, accounting for 92.7% of the energy consumption of the whole Greater Bay Area. From the perspective of major cities, the total comprehensive energy consumption in Guangzhou and Shenzhen is 63 Mtce and 46 Mtce respectively, accounting for 24% and 17.4% of the total comprehensive energy consumption in the Guangdong-Hong Kong-Macao Greater Bay Area, adding up to 41.4%. The total comprehensive energy consumption of Dongguan, Foshan, and Huizhou is 31 Mtce, 30 Mtce, and 28 Mtce respectively, and the total comprehensive energy consumption of the remaining six cities is less than 20 Mtce. From the perspective of carbon emissions, in recent years, the carbon emissions of Hong Kong and Macau have been relatively stable, and have entered the peak fluctuation range of carbon emissions. Many cities in Guangdong Province put forward the development goal of carbon peaking during the 14th Five-Year Plan period, playing a leading demonstration role in the field of carbon neutrality. Specifically, low-carbon pilot cities such as Guangzhou, Shenzhen, and Zhongshan have set targets for carbon peaking emissions in 2020, 2020-2022, and 2023-2025, respectively, ahead of China's overall target of carbon peaking emissions by 2030.

Industrial structure optimization to guide low-carbon development of cities

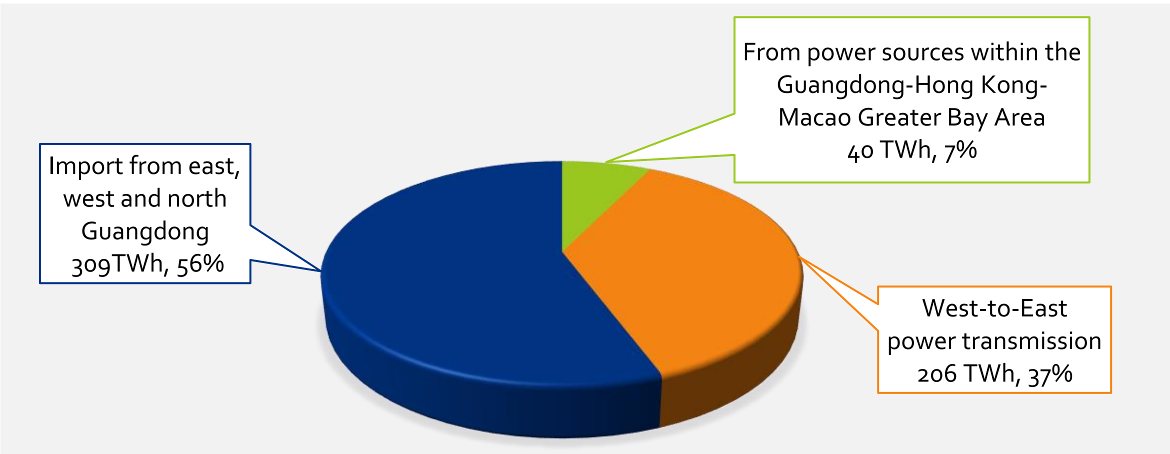
Due to the relatively high proportion of tertiary industry in cities, the carbon emissions per unit of GDP in the Guangdong-Hong Kong-Macao Greater Bay Area are lower than in other regions. In 2020, the tertiary industry in Hong Kong and Macau accounted for 93.7% and 95.7% of the GDP respectively. Secondly, the tertiary industry in Guangdong and Shenzhen accounts for more than 60%, and the development of the service-oriented economy has already reached a certain scale. On this basis, the proportion of energy used by the tertiary industry in cities such as Guangzhou, Shenzhen, and Macau in 2020 was all higher than 40%, and the corresponding carbon emissions per unit of GDP in these cities were relatively low. According to the *Annual Research Report on Carbon Neutrality in Guangdong-Hong Kong-Macao Greater Bay Area*, among the cities in the Guangdong-Hong Kong-Macao Greater Bay Area, Macao has the lowest carbon emissions per unit of GDP, followed by Shenzhen, Hong Kong, and Guangzhou, the carbon emissions per unit of GDP in these three cities are comparable to those of countries such as the United Kingdom and Norway, and slightly lower than the United States. The industrial structure of cities such as Jiangmen and Huizhou is still dominated by manufacturing. In 2020, the proportion of energy used by the secondary industry in these cities exceeded 50%, so their carbon emissions per unit of GDP are 30% to 50% higher than the average level of China.

Regional collaboration to help clean energy use in the Greater Bay Area

The supply of clean energy in the Guangdong-Hong Kong-Macao Greater Bay Area accounts for more than 60%. In 2020, among the power supply in the Greater Bay Area, the clean power in the region accounted for about 58.7%, about 181.2 TWh. About 74% of the electricity transmitted through the West-to-East Power Transmission was clean energy, about 153 TWh. Even excluding the clean power sent to the Greater Bay Area from other places of Guangdong Province, the proportion of clean energy in the Guangdong-Hong Kong-Macao Greater Bay Area has already reached 60% in 2020.

The local power supply in the Guangdong-Hong Kong-Macao Greater Bay Area is insufficient, and the West-to-East Power Transmission and coordination within the province play an important role. In 2020, the total electricity consumption in the Guangdong-Hong Kong-Macao Greater Bay Area was 554.5 TWh, of which 308.7 billion TWh was supplied within the area, accounting for only 55.7% of the total electricity consumption Greater Bay Area. Under the circumstance that the inefficient electricity production in the area, 44.3% of the total electricity consumption in the Guangdong-Hong Kong-Macao Greater Bay Area comes from regional cooperative supply, of which 205.8 TWh is from the West-to-East Electricity Transmission, accounting for 37.1%. In addition, the electricity transmission from eastern, western, and northern Guangdong to the Guangdong-Hong Kong-Macao Greater Bay Area in 2020 was about 40 TWh, accounting for 7.2% of the total electricity consumption. During the 14th Five-Year Plan period, in terms of promoting the coordinated development of energy in the Guangdong-Hong Kong-Macao Greater Bay Area, the *14th Five-Year Plan for Energy Development in Guangdong Province* further proposed that guided by "what the Bay Area wants, what Hong Kong and Macao needs, and what Guangdong can do", to actively promote the coordinated development of energy in the Guangdong-Hong Kong-Macao Greater Bay Area, and form a pattern of overall coordination, interconnection, complementary advantages, and win-win cooperation between Guangdong, Hong Kong, and Macao.

Figure 9 The proportion of electricity supply in the Guangdong-Hong Kong-Macao Greater Bay Area in 2020.



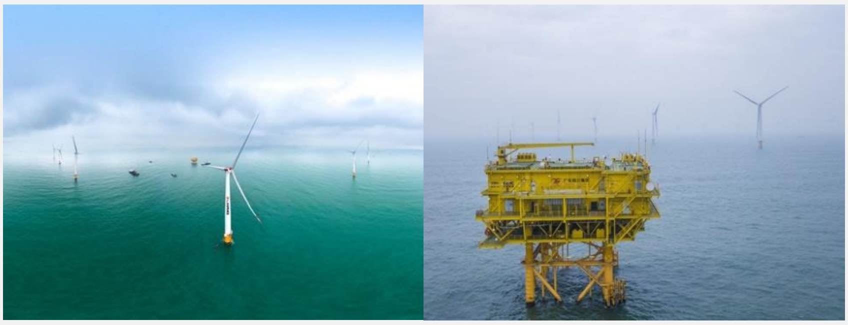
The scale of offshore wind power installations has been growing rapidly

In 2020, the new energy power generation in the Guangdong-Hong Kong-Macao Greater Bay Area was 16.4 TWh, an increase of 18% year-on-year, accounting for 5.4% of the total power generation, an increase of 4 percentage points over 2010. At the same time, the Greater Bay Area has made full use of its geographical advantages and resource endowments in coastal areas, and the scale of installed offshore wind power has achieved rapid growth. In 2020, the installed capacity of wind power in Guangdong Province reached 5.65 GW, an increase of more than 8 times compared with 620 MW in 2010. Among them, offshore wind power is showing rapid growth. By the end of 2020, the installed capacity of offshore wind power grid-connected in Guangdong Province reached 1.01 GW, a year-on-year increase of 257%.

Box 6 Introduction to Offshore Wind Power Development in Guangdong-Hong Kong-Macao Greater Bay Area

As the development of offshore wind power gradually moves from offshore to the open sea, the Guangdong-Hong Kong-Macao Greater Bay Area has broken through the technical bottleneck of offshore wind power transmission in offshore deep-water areas and open sea areas, mastered the key technologies of open sea wind power transmission, and has possessed the research and development and integrated supply capabilities of related wind power equipment, and provided technical and experience reference for offshore wind power in other regions of the country. At 11:18 on April 2, 2021, all 55 wind turbines of the Zhuhai Jinwan Offshore Wind Farm Project, a subsidiary of Guangdong Energy Group, were connected to the grid for power generation. As the second batch of key offshore wind power projects in Guangdong Province, since the first wind turbine was connected to the grid and put into operation on November 18, 2020, it took less than five months to achieve full capacity connection to the grid and operation. It is currently the largest offshore wind farm under construction in the Guangdong-Hong Kong-Macao Greater Bay Area. Calculated based on standard coal for thermal power generation, it can save 229,600 tce and reduce carbon dioxide emissions by 456,300 tons every year.

Figure 10 A glimpse of the Zhuhai Jinwan Offshore Wind Farm Project



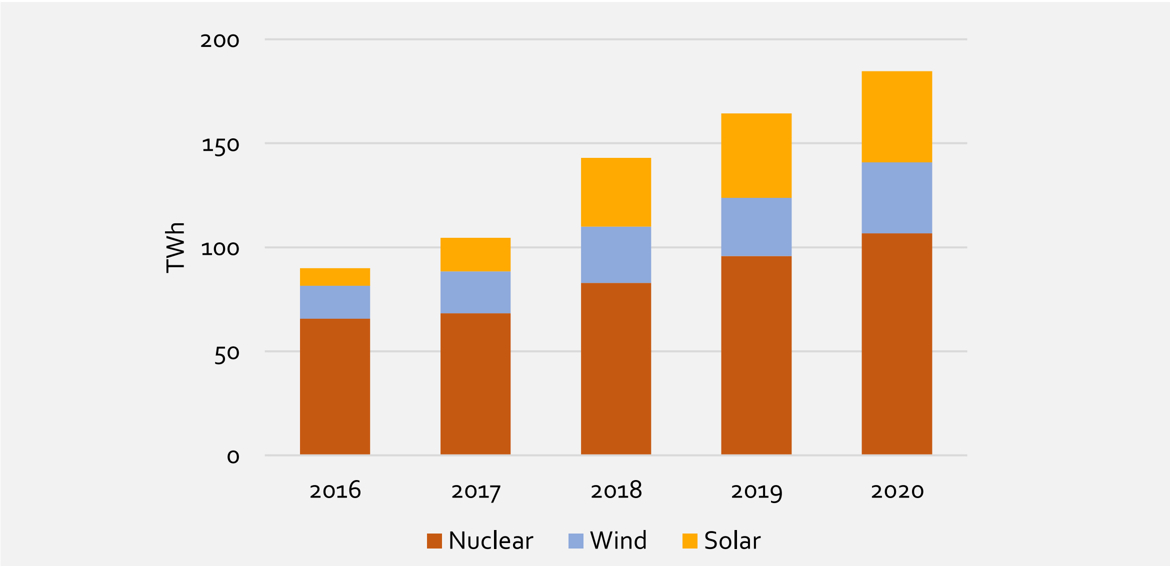
Source: State-owned Assets Supervision and Administration Commission of the Government of Guangdong Province

3.3 The Region of the Yangtze River Delta

The Yangtze River Delta region is one of the regions with the most active economic development, the highest degree of openness, and the strongest innovation capability in China. The Yangtze River Delta region includes three provinces and one city, that is Shanghai, Jiangsu Province, Zhejiang Province, and Anhui Province, with an area of 358,000 square kilometers, a total population of 235 million, a total GDP of 24.5 trillion yuan in 2020. It brings together 16.7% of the country's population and creates 24.2% of the total economic output within 3.7% of the country's land area, and overall labour productivity ranks at the forefront of the country. The *Outline of the Integrated Development Plan of Yangtze River Delta Region* issued in December 2019 proposed the strategic positioning of the Yangtze River Delta region's development before 2035, that is, to become "a strong and active growth pole of national development, a national model area for high-quality development, the first to basically realise the modernisation, leading the regional integrated development demonstration area and the new highland of reform and opening up in the new era".

The Yangtze River Delta region is not only one of the regions with the most concentrated energy consumption in China but also one of the regions with the least energy resources. In recent years, the development and utilisation of clean and low-carbon energy has grown rapidly here. Due to the lack of traditional energy resources, the Yangtze River Delta region is highly dependent on energy input from other provinces, as the main destination for major cross-provincial and cross-regional energy infrastructure projects such as North-to-South Coal Transportation, West-to-East Gas Transmission, and West-to-East Power Transmission, the proportion of transmitted power continues to be high. In 2020, the electricity consumption in the Yangtze River Delta region accounted for 20.3% of the country's total, and the per capita annual electricity consumption was 5,551 kWh, which is 1.2 times the national average. The wind power, solar PV, and nuclear power generation in the three provinces and one city has reached 34.1 billion kWh, 43.8 billion kWh, and 106.8 billion kWh respectively, and the average annual growth rate during the 13th Five-Year Plan period was 21%, 51%, and 12.9%.

Figure 11 Low-carbon power generation in the Yangtze River Delta region from 2016 to 2020



Source: China Energy Statistical Yearbook, ERI of NDRC

Construction of distributed renewable power generation positions

The industrial parks in the Yangtze River Delta region are concentrated, with abundant factory rooftops, and there are also a large number of fishery waters and agricultural greenhouses, which provide a good opportunity for the development of distributed solar PV. By the end of 2019, Jiangsu, Zhejiang, and Shanghai had developed a total of 16.9 GW of distributed solar PV, accounting for 27% of the total installed capacity of distributed solar PV in the country, and they are one of the key areas of distributed solar PV. According to relevant research and assessments[5], the installed capacity of distributed solar PV in Jiangsu, Zhejiang, and Shanghai can reach 180 million to 200 GW, and the development potential of distributed wind power is about 32.6 million to 82.7 GW. However, currently limited by the distribution network structure and operation mode of the grid, the carrying capacity of the distributed power grid connected to the grid is still far less than the development potential.

Steadily promote the large-scale development of offshore wind power. The Yangtze River Delta, Shandong Peninsula, Southern Fujian, Eastern Guangdong, and Beibu Gulf are the five major offshore wind power bases in China. In 2021, the Jiaxing No. 2 offshore wind power transmission project was officially put into operation in Pinghu, Zhejiang, and the Jiaxing No. 1 and Shengsi No. 2 wind power projects, which were integrated into the Jiaxing power grid, also entered the final commissioning stage. The three together form the largest offshore wind power cluster under construction in the Yangtze River Delta, with a total of 188 wind turbines installed and a total installed capacity of 1 GW.

Relying on pumped-hydro storage to improve the stability of new energy supply.

The pumped-hydro storage power stations in Zhejiang and Anhui are responsible for peak shaving, valley filling and energy storage in the East China Power Grid. Zhejiang is currently the province with the largest number of pumped-hydro storage projects in the country. There are 5 pumped-hydro storage power stations in operation, 7 projects under construction, and more than 20 projects to be built still in the planning, and site-selection stages[6] . In addition to large-scale power stations, many areas in Zhejiang Province are also planning to build small and medium-sized pumped-hydro storage power stations. Anhui Province has built and put into operation 4 pumped storage power stations with an installed capacity of 3.48 GW, ranking third in the country; by 2025, 2030, and 2035, the cumulative installed capacity of pumped storage power stations in the province is expected to reach 4.68 GW, above 10 GW and above 16 GW respectively.

Create a sample of cross-regional integrated low-carbon development

Relying on the integrated development layout, the Yangtze River Delta promotes the interconnection of new regional power infrastructures such as UHV, distribution networks, and hydrogen energy. The Yangtze River Delta has taken the lead in building the UHV backbone grid structure in the country. In September 2020, the Jiashan-Qingpu 10kV power tie line project was completed and put into operation, and the Qingpu-Wujiang 10kV interconnection project was also officially completed, realising the cross-provincial interconnection of the distribution network between Shanghai, Zhejiang, and Jiangsu, marking the entry of a new stage of integrated cross-regional power development[7] . In June 2020, four energy companies from the three provinces and one city in the Yangtze River Delta jointly signed the *Framework Agreement of Energy Infrastructure Integration Cooperation of the Yangtze River Delta*. planning to establish a cooperation mechanism for energy enterprises in the Yangtze River Delta, to promote the interconnection of energy infrastructure between regions, and build a demonstration route of hydrogen energy logistics in the Yangtze River Delta. In recent years, a large number of new energy technologies, new models, and new formats such as "Internet +" smart energy, energy storage, blockchain, and comprehensive energy services in the Yangtze River Delta region have flourished, promoting the establishment of an energy system with integrated optimization, regional linkage, intelligent regulation, and physical information fusion and promote regional innovation and development.

In October 2022, the Yangtze River Delta Demonstration Zone of Ecological and Green Integrated Development located at the junction of Shanghai, Jiangsu, and Zhejiang released the *Implementation Plan for Carbon Peaking and Carbon Neutrality in the Yangtze River Delta Demonstration Zone of Ecological and Green Integrated Development* and *Near-zero Carbon Emission Special Plan of Water Town Living Room*. It is proposed that by 2025, the energy consumption intensity of the demonstration area will be reduced by about 15% compared with 2020, and the carbon emission intensity will be reduced by more than 20% compared with 2020. The document proposes to actively promote the pilot test of green and low-carbon advanced technologies, and vigorously promote the application of distributed solar PVs, ground (water) source heat pumps, hydrogen energy, biomass energy, near-zero carbon emission buildings, and other technical facilities. The construction of "Three Gardens" (Jiangnan polders, mulberry fish ponds, and water town wetlands) focuses on near-zero carbon emission buildings, low-carbon recycling stereoscopic agriculture, etc., vigorously implements humidification and green expansion, continuously improves carbon sink capacity, and strives to build a low-carbon development sample of the Yangtze River Delta.

The new energy industry has become the "green engine" of economic development

According to their respective resource endowments and industrial bases, the three provinces and one city in the Yangtze River Delta region jointly face the huge market demand for energy transformation and have created a new energy industry ecology that integrates technology industries. According to Xinhua Daily, large-scale power equipment in the Yangtze River Delta accounts for about 1/3 of the country's total output, solar cell output accounts for about half of the country's output, and offshore wind turbine output accounts for 60% of the country's total.[8] Among them, Jiangsu Province has a complete solar PV industry chain and wind power complete machine manufacturers. With the scale of distributed solar PV installations ranking second in the country, it has established an internationally competitive solar PV industry chain, the output of silicon wafers, crystalline silicon cells, and crystalline silicon modules accounts for more than 40% of the country's total. Shanghai plays a leading and demonstrative role in new energy technology research and development and international marketing, Zhejiang Province has outstanding features in the solar PV industry and nuclear power parts industry, and Anhui Province leads the way in new energy electrical products and biomass power generation applications.

3.4 The Region of Beijing-Tianjin-Hebei

This region contains Beijing, Tianjin, and Hebei. The three are geographically connected, with close interactions in economic development, and inseparability of the ecological environment, forming an ecological community with a common destiny. The Beijing-Tianjin-Hebei region is one of the three most dynamic economic growth poles in China. Its overall positioning is "a world-class urban agglomeration with the capital as the core, a leading area for the overall coordinated of regional development and reform, a new engine for national innovation-driven economic growth, and a demonstration area for ecological restoration and environmental improvement."

Taking multiple measures to jointly control the smog

Ten years ago, the urban energy of Beijing-Tianjin-Hebei was dominated by coal, and the total coal consumption continued to increase, environmental pollution was getting worse, and the region suffered serious smog. In this context, the *Beijing-Tianjin-Hebei Coordinated Energy Development Plan (2016-2025)* was proposed to break the restrictions of administrative regions, promote the revolution of energy production and consumption, and promote green, circular and low-carbon development. Beijing has taken multiple measures to control smog, especially vigorously supporting new energy vehicle companies, accelerating the improvement of vehicle exhaust treatment technology, and accelerating the improvement of vehicle fuel quality. Tianjin fully promoted "replacing coal with electricity" and "replacing oil with electricity" to support smog control in Hebei. Hebei Province actively promoted pollution control in key industries such as iron and steel, electric power, cement, and petrochemicals, and actively promoted clean production and comprehensive utilization of resources. In addition, the Beijing-Tianjin-Hebei region took the lead in establishing an ecological environment monitoring system and database and joint environmental protection law enforcement and took measures to strictly control, manage, and shut down energy-intensive and high-polluting enterprises to force their structural transformation.

Acceleration of replacing coal with new energy

In recent years, the Beijing-Tianjin-Hebei region has accelerated the promotion of clean energy replacement, and the coal-based energy structure has gradually shifted to a diversified and clean one. During the "13th Five-Year Plan" period, Beijing's coal consumption has been greatly reduced from 11.65 million tons in 2015 to 1.73 million tons in 2020, and the proportion of coal in energy consumption has dropped from 13.7% to 1.9%. [9] The plain areas of Beijing have become virtually coal-free. Except for the use of anthracite in the mountainous areas of Tianjin, other areas of the city have removed the use of scattered coal for heating. The scattered heating coal in rural areas in the plain and rural areas of Hebei Province has also been cleared[10]. By the end of 2020, Beijing-Tianjin-Hebei (including Beijing-Tianjin-Tangshan Power Grid and Hebei Southern Power Grid) had a total installed capacity of 133 GW of new energy and a total of 820.1 billion kilowatt-hours of new energy power generation. The installed capacity and power generation of new energy accounted for 36.1% and 7.54% respectively. In the northern Hebei region where new energy installed capacity is concentrated, by the end of 2020, the installed capacity of new energy accounted for 54.29%, and its power generation accounted for nearly 15%[11].

Market mechanism promotes clean energy consumption in Beijing-Tianjin-Hebei

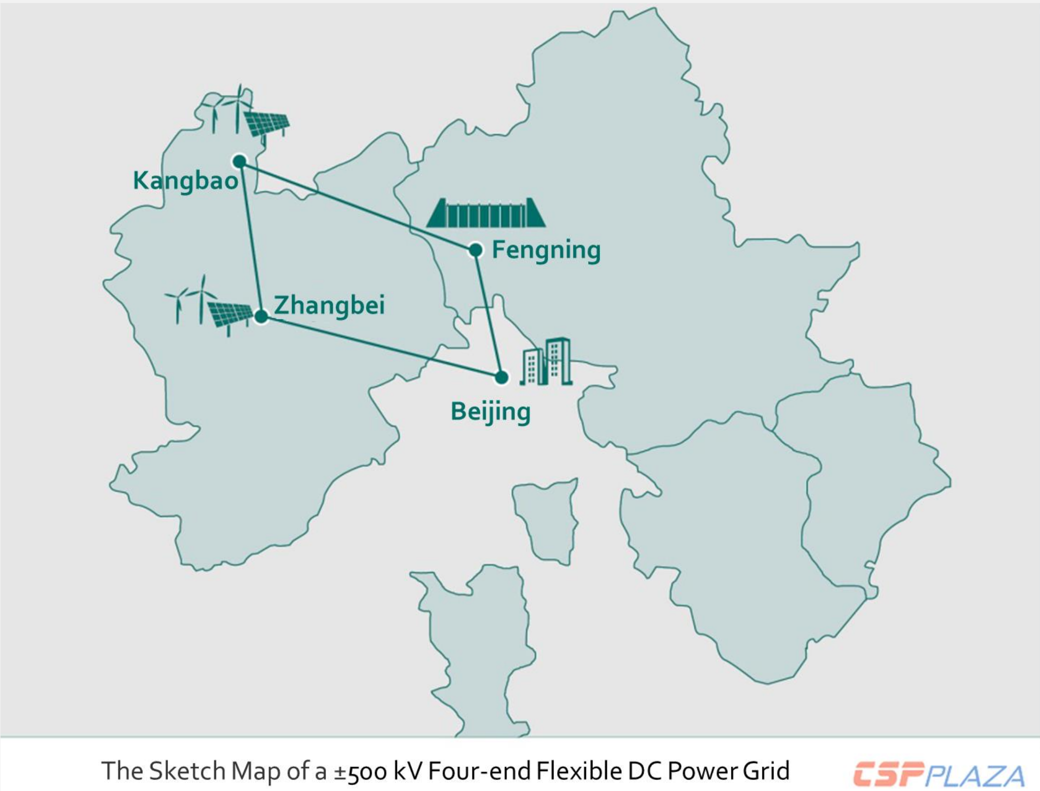
On December 30, 2020, the North China Supervision Bureau of the National Energy Administration issued the *Market-oriented Trading Rules of Green Power in the Beijing-Tianjin-Hebei Region* and its supporting priority scheduling implementation rules, to fully coordinate the imbalance between the production and consumption of new energy power in the provincial power grids in the Beijing-Tianjin-Hebei region, to realise efficient consumption of clean energy and reasonable pricing of new energy power generation by market-oriented means, and to help the clean and low-carbon transformation of the energy structure of the Beijing-Tianjin-Hebei region. In terms of specific mechanisms, the first is to focus on the role of the market in optimising the allocation of resources based on the guaranteed purchase policy of new energy consumption; the second is to stimulate the enthusiasm of new energy stations to participate in the market and provide convenience for users or electricity sales companies to sign contracts with new energy fields stations.

Box 7 Zhangbei Flexible DC Grid Test Demonstration Project

The Zhangbei Flexible DC Grid Test Demonstration Project was built by the State Grid. It is the world's first flexible DC power grid project, and currently the flexible DC project with the highest voltage level and the largest transmission capacity in the world. The project officially started construction on February 28, 2018, and was officially put into operation in June 2020. It can deliver 14 billion kWh of clean electricity to Beijing every year, which is equivalent to 1/10 of Beijing's annual electricity consumption [12], greatly improving Zhangjiakou's clean energy transmission capacity and effectively solving the consumption problem of tens of thousands of kilowatts of clean energy in Zhangbei.

The Zhangbei Flexible DC Grid Test Demonstration Project is a four-terminal flexible DC grid that collects and transmits large-scale wind power, solar PV power, energy storage, pumped storage, and other forms of energy. Relying on 666 km ± 500 kV DC transmission lines, the project builds four new converter stations in Zhangbei, Kangbao, Fengning, and Beijing, with a maximum transmission capacity of 4.5 GW and a total converter capacity of 9 GW.[13]

Figure 12 Schematic diagram of Zhangbei flexible DC Grid Test Demonstration Project



Source: CSP Plaza

3.5 The Region of Yellow River Basin

With a total area of 800,000 square kilometers, the Yellow River Basin spans four major landform units and three major terrain steps in China, including the Qinghai-Tibet Plateau, Inner Mongolia Plateau, Loess Plateau, and North China Plain. It is not only a traditional resource-intensive area but also an area with the heaviest energy transformation task in China. The coal-bearing area of the Yellow River Basin is over 357,000 square kilometers, and its economic recoverable coal resources and coal output are currently the largest in China; 9 of the 14 large-scale coal production bases planned by the state are distributed along the Yellow River.

The *Outline of the Yellow River Basin's Ecological Protection and High-quality Development Plan* calls for adhering to ecological priority and green development, adjusting the regional industrial layout, developing emerging industries, promoting clean production, and firmly taking the road of green and sustainable high-quality development. At present, with the accelerated construction of large-scale wind power and solar PV base projects focusing on deserts and gobi areas, the installed capacity of wind power and solar PV of the Yellow River Basin has reached 140 GW and 120 GW, accounting for 46.7% and 43.3% of the national total. China's first million-ton project of carbon dioxide capture, utilisation, and storage was completed in Shandong Shengli Oilfield, which locates by the Yellow River estuary.[14]

Governing coal mining subsidence areas with solar PV development [15, 16]

The combination of coal mining subsidence management and solar PV provides an important way for the transformation of traditional energy regions. In 2015, Shanxi Province in the middle reaches of the Yellow River began to explore the use of solar PV to manage coal mining subsidence areas. In 2016, the state planned to build 5.5 GW of solar PV leading bases, of which 4.5 GW were combined with coal mining subsidence management. The first batch of solar PV leader bases was implemented in the coal mining subsidence area of 1687.8 square kilometers formed in the Xinrong District and Zuoyun County, southern suburbs of Datong City, in northern Shanxi Province. In recent years, Datong has built solar PV power stations in coal mining subsidence areas relying on abundant solar energy resources and simultaneously carried out ecological management such as planting in solar PV fields and backfill areas. At present, a 150,000-kilowatt solar PV base for controlling coal mining subsidence areas has been built. Given the actuality of idle land and fragile ecological vegetation in coal mining subsidence areas after the relocation of residents, various development models of solar PV power stations, such as the complementation of agriculture and solar PV, and the complementation of forestry and solar PV, can promote the ecological management of mining areas, and alleviate the contradiction of solar PV power station land use through comprehensive utilisation of waste mines.

Solar PV and wind power bases in the desert and gobi desert [17]

The construction of large-scale wind power and solar PV bases in the desert and gobi desert areas can give full play to the advantages of wind and solar power resources as well as the good conditions for construction in these areas. Solar PV sand control is the latest achievement in recent years. The laying of solar PV modules can not only protect the land against wind, but also absorb light, reduce land temperature, reduce soil moisture evaporation, and increase soil moisture accumulation, to achieve the double benefit of high efficiency of solar energy resources in desert areas while turning the desert into an oasis. The first batch of large-scale wind power and solar PV base projects of about 100 GW focusing on the desert, Gobi and desert areas, mainly distributed in Inner Mongolia, Qinghai, Gansu, Ningxia, Shaanxi, Xinjiang 6 provinces (regions), and have all started construction. The second batch of large base projects, focusing on the Kubuqi, Ulanbuhe, Tengger, and Badain Jaran deserts, supplemented by other deserts and gobi areas, comprehensively considering coal mining subsidence areas, with a total scale of about 455 GW, will be completed in the 14th Five-Year Plan and 15th Five-Year Plan period.

The multi-energy complementary base of hydro-wind-solar power in Qinghai

In recent years, Qinghai Province on the upper Yellow River has made great efforts to promote the development of clean energy, the construction of new power systems, the construction of multiple energy storage systems, and to build a national-level solar PV power generation and wind power base. In 2016, President Xi Jinping proposed to "make Qinghai an important new energy industry base in the country" during his inspection of Qinghai. When he inspected Qinghai in 2021, he further clarified the higher goal of "building a national clean energy industry highland". By the end of 2021, the province's installed power capacity reached 42.9 GW, with clean energy accounting for 90.8% and new energy accounting for 61.4%, ranking first in the country for both indicators. In the first half of 2022, Qinghai's clean energy power generation accounted for 84.8% of the province's total power generation, of which new energy power generation such as wind power and solar PV accounted for 42.3%, and the number of days when the daily power generation of new energy exceeded that of hydropower was 96 days.[18]

Clean heating in the source region of the Yangtze River, Yellow River, and Lancang River [19]

The source region of the three rivers in Qinghai Province is the plateau wetland with the highest altitude and the largest area in the world, and it is also an important water conservation area in China. For a long time, this region has mainly relied on burning coal and cow dung for heating, which has low energy efficiency and low heating value, resulting in pollution emissions. The construction and renovation project of smart energy-use clean heating in the source region of the three rivers was launched in May 2020. By the principle of pilot first, classified and step-by-step implementation, the traditional coal-fired burners were gradually transformed into efficient and clean electric boilers. According to the experience of the clean energy pilot, Qinghai has formed a clean heating renovation plan with strong operability, which has been implemented first in public places such as schools and health services, from cities and towns, and then in rural and pastoral areas.

Shandong's solar PV installed capacity ranks first in China [20]

Shandong Province is located in the lower reaches of the Yellow River. As the country's leading pilot area for old-to-new kinetic energy conversion, with the active implementation of the policy of "promoting solar PVs at a whole-county level", the installed solar PV capacity of households in Shandong Province has been at the leading level in China for many years. In 2021, Shandong Province has added 10.7 GW of new grid-connected solar PV capacity, making it the only province with over 10 GW of solar PV capacity, and accounting for 19.5% of the country's new grid-connected capacity. The cumulative installed capacity of solar PV power generation in Shandong reached 33.4 GW, ranking first in the newly installed and cumulative installed capacity of solar PVs in all provinces across the country. According to data from the NEA, the newly installed capacity of household solar PV projects included in the scale management indicators in 2021 was 21.6 GW, with Shandong Province ranking first. In the first half of 2022, Shandong added 3.7 GW of grid-connected capacity, of which distributed solar PV was 3.4 GW, ranking first in the country again. Among them, the newly installed capacity of household distributed solar PV was 1.9 GW, ranking third in the country. As of the end of June 2022, the cumulative installed capacity of solar PV power generation in Shandong reached 37.1 GW, maintaining a leading position in the country.

Chapter 4

Key Conclusions from the 2060 Energy Sector Carbon Neutral Outlook

4 Key Conclusions from the 2060 Energy Sector Carbon Neutral Outlook

The purpose of the *China Energy Transition Outlook 2023* is driven by the realisation of the carbon neutrality pledge by 2060 and guided by the action of carbon peaking before 2030. On the basis and analysis of the new changes in the global energy transition situation and the new achievements in China's energy transition, three technical paths for the development of the energy system are designed, researching and prospecting China's 2060 energy system using scenario analysis and a self-developed model decision support system. This special report mainly introduces the key conclusions of Carbon Neutrality Scenario 1 (**CNS1**) and Carbon Neutrality Scenario 2 (**CNS2**).

4.1 Two technology roadmaps for China to achieve carbon neutrality

The *China Energy Transition Outlook 2023* designs three scenarios, including the **BLS**, the **CNS1**, and the **CNS2**. All three scenarios meet the environmental protection objectives and energy system security objectives and incorporate the policies, measures, and standards that have been issued. The difference is that **BLS** deduces future energy development trends based on the current development of the energy sector, combined with recent internal and external environments and risks. Both **CNS1** and **CNS2** need to achieve the carbon peak by 2030 and carbon neutrality[1] by 2060, that is, research under the pressure of the goal and propose two transformation solutions.

- **CNS1:** The annual operating hours of the active coal-fired power units should be gradually reduced, implementing natural decommissioning measures, with the last coal-fired power unit running until around 2055; moderately deploy the technology of carbon negative in the medium and long term, with the development of new energy storage technologies, electric vehicle energy storage (V2G), green hydrogen and other new technologies, the energy system can achieve net zero carbon emissions around 2055.
- **CNS2:** Accelerate the development of new energy with greater efforts, especially the development of wind power and solar PV, so as to accelerate the replacement of existing coal power; at the same time, the commercial application of new energy storage technologies, electric vehicle energy storage (V2G), green hydrogen (including storage and transportation) and other new technologies expands at a faster rate, with more powerful supporting measures for new business models and new development formats, to achieve net zero carbon emissions by 2055.

4.2 China's energy transformation is driven by the need to ensure a clean, carbon-neutral, safe, and efficient energy system

The overall target for the energy transformation is to develop a clean, low-carbon, safe and efficient energy system. The clean energy system will not pollute the air, water and soil, the safe energy system will ensure security of energy supply, and the efficient energy system will use energy efficiently while ensuring a cost-efficient energy supply. Furthermore, it is important that the transformation process ensures a just transformation, where people's livelihoods are ensured and further improved.

[1] The definition of "*carbon neutrality*" for CETO2023 is proposed to follow the description in the new published *Carbon Peaking and Carbon Neutrality Cadre Readings*, which includes only carbon dioxide neutrality. See "Knowledge Links" on page 13 of the *Carbon Peaking and Carbon Neutrality Cadre Readings*: Carbon neutrality is "the offsetting of anthropogenic carbon dioxide emissions from a country or region over a specified period of time with carbon dioxide removed through afforestation, carbon capture, storage and utilization (CCUS), and sequestration".

Specifically, regarding carbon emissions, both scenarios ensure that China's CO_2 emissions from the energy sector will peak before 2030 and then gradually decline. In the CNS2 scenario, net-zero carbon emissions are achieved before 2055, which will provide a strong guarantee that China's economic and social systems will be carbon neutral by 2060.

4.3 Energy efficiency, electrification and green power supply are the main elements in the transformation

As a basic assumption, the Chinese economy is expected to grow by a factor of 4 from 2020 to 2060. To support this growth under the carbon emission constraints, the energy system must be much more efficient than at current. The key here is energy efficiency in the end-use sectors and reduction of losses in the energy supply sectors. In the end-use sectors, shifting from fossil fuels to electricity will be one of the most important steps in the transformation process, ensuring high efficiency and low environmental impact.

In the power sector, rapid and massive deployment of wind and solar power is needed to meet the increasing demand for electricity and to gradually phase down the use of coal-fired power plants. The role of coal power will gradually shift to be a flexibility provider to support the variable power production from wind and solar.

The share of non-fossil energy (including hydrogen) in total primary energy will continue to rise, and non-fossil energy will become the main energy source in China between 2040 and 2045. In the CNS2 scenario, the share of non-fossil energy is expected to reach around 40% by 2035; and more than 95% by 2060. Of this, renewable energy will cover more than 90% of the primary energy consumption.

The substantial changes in the energy system are illustrated in the differences in the energy flows for 2020 and 2060, as shown in Figure 1 and Figure 2. The total final energy consumption is less in 2060 than in 2020 due to electrification and energy efficiency measures, the losses in the power sector are minimised due to a large amount of solar and wind power, and the overall coal consumption is heavily reduced to ensure carbon neutrality before 2060.

Figure 13 2020 China energy flow chart

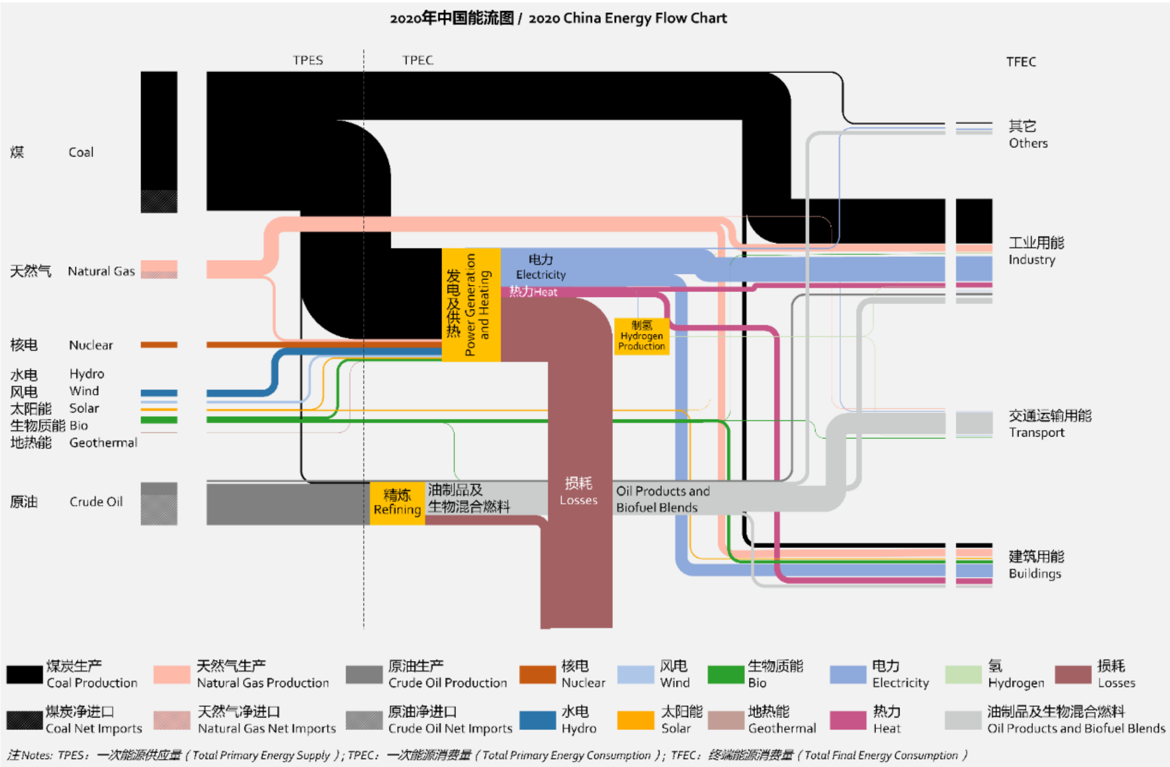
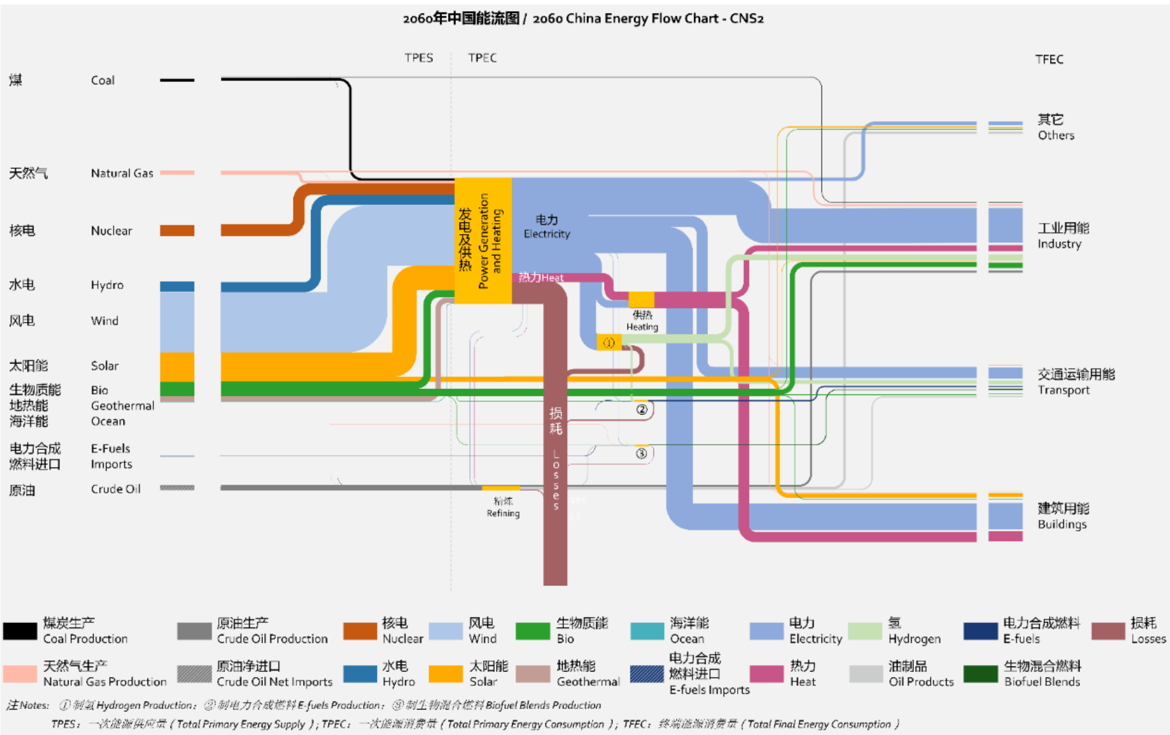


Figure 14 CNS2 2060 China energy flow chart



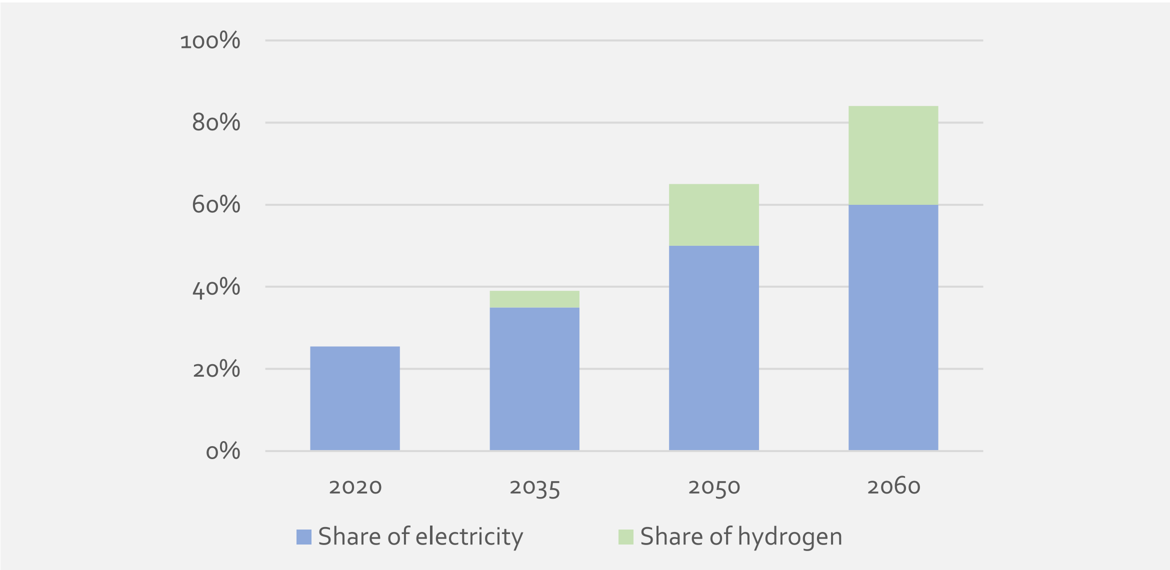
4.4 Electrification and energy efficiency help to achieve a decarbonised end-use energy mix

The structure of end-use energy is being optimised, and the share of electricity and hydrogen consumption in the building, industrial and transport sectors and other areas increases gradually.

In the building sector, as economic and social development and people's living standards improve, end-use energy consumption will continue to grow and gradually peak as energy efficiency continues to improve, and then slowly decline, with differences only in the timing and magnitude of the peak between the two CNS scenarios. The large-scale promotion of ultra-low/near-zero energy buildings, the application of renewable energy in buildings and the increase in the electrification rate will all help to slow down the trend of increasing energy consumption in the building sector. In 2060, the electrification rate in the building sector will be around 85-90%.

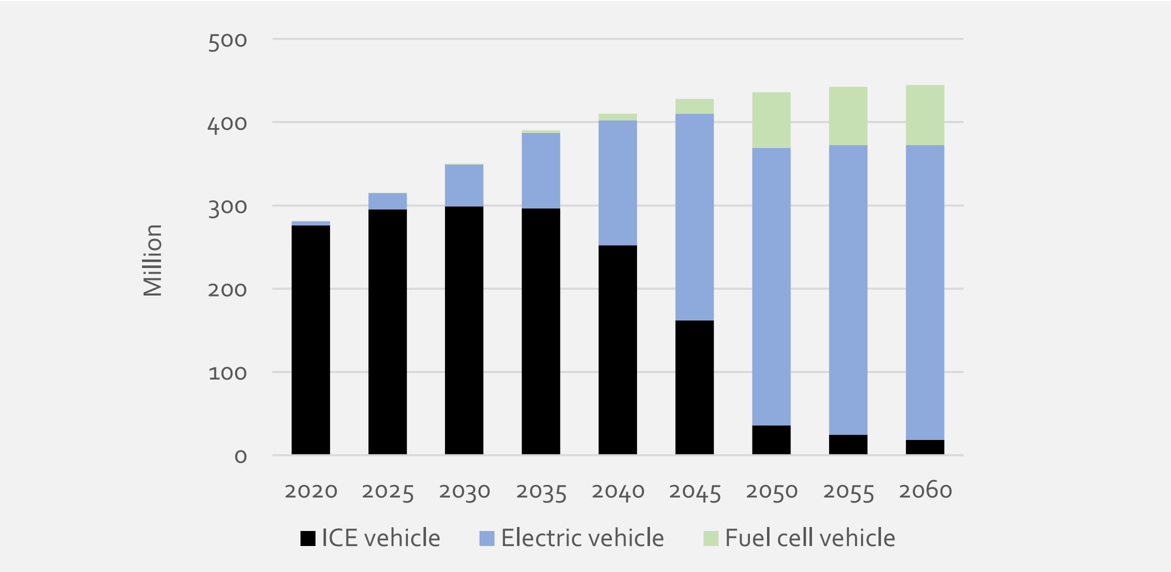
The industry sector is a key area for the decarbonisation of end-use consumption. The phase-out of outdated production capacity in the steel and cement sectors and the orderly development of the coal chemical industry will lead to a steady decline in coal consumption, with industrial energy consumption stabilising and expected to peak around 2030. In the CNS2 scenario, the industry's share of end-use energy consumption will be less than 50% in 2060, due to significant energy efficiency improvements, the introduction of new technologies, device shifting, and a large-scale application of electricity and green hydrogen.

Figure 15 The projected share of electricity and hydrogen in industrial end-use energy demand in the CNS2 scenario



In the transport sector, carbon emissions start to decline after 2035. The number of electric vehicles increases rapidly, and almost all passenger cars are electric or hydrogen fuel cell vehicles in 2060. The development of hydrogen fuel cell vehicles is mainly for heavy commercial vehicles and buses. The electrification rate of railways will be further increased to over 80% by 2030 and 100% by 2050. The large-scale utilisation of biofuels and Power-to-X (PtX) in the aviation industry will also play an important role in the low-carbon development of the transport sector.

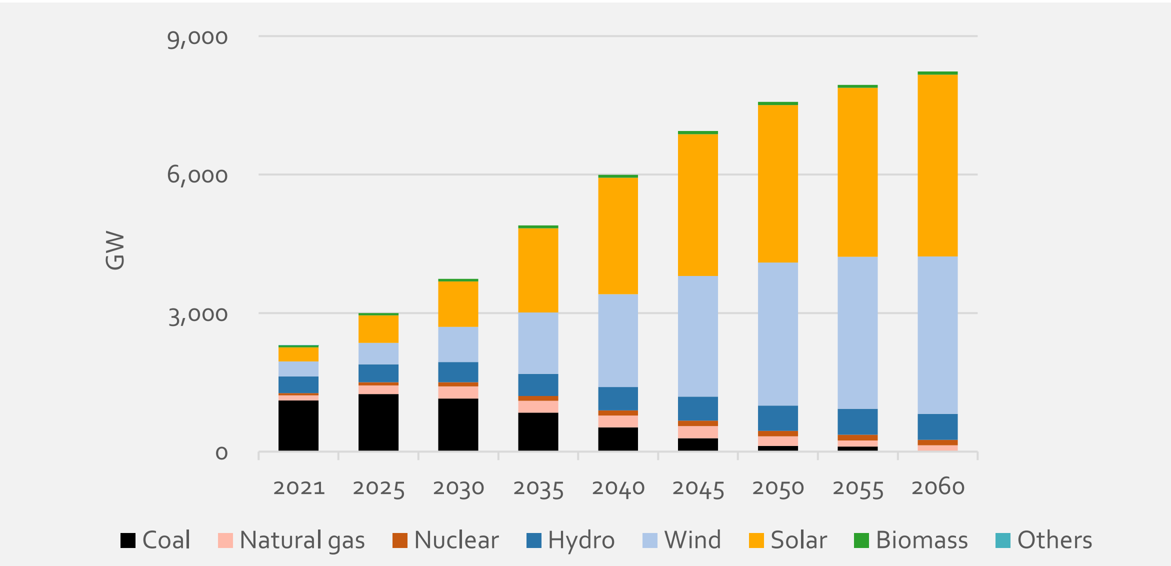
Figure 16 Projections of China's vehicle ownership and fuel mix in the CNS2 scenario



4.5 Wind and solar power dominate the power sector, covering more than 90% of the electricity consumption

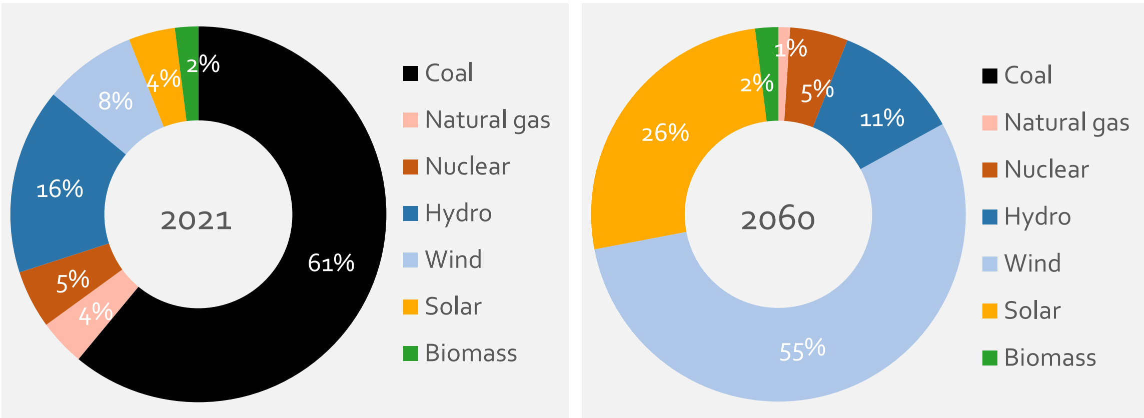
China's installed power generation will continue to grow, due to the electrification of the end-use sectors, and in 2060 the installed capacity in the power sector will be more than 8000 GW. Wind and solar power will gradually become the backbone of the energy system.

Figure 17 2021-2060 Installed power generation capacity in the CNS2 scenario



The share of renewable energy generation will reach more than 50% by 2035; thereafter, with the accelerated retirement of coal power, the share will rise further to more than 90% of the power generation by 2060.

Figure 18 Power generation structure in the CNS2 scenario



4.6 Pumped storage and new energy storage will be the main guarantee of the secure and stable operation of new power systems in the long term

In the future, in a new power system dominated by new energy sources, the share of coal-fired power generation will be significantly reduced, and flexible resources on the power supply side, grid side and customer side will be applied on a large scale. The operational stability of the power system will be ensured in an economically optimal manner when fluctuating power sources such as wind and solar power are generating large amounts of electricity. Pumped storage and energy storage batteries will play the most significant regulation role in the 2060 balance of electricity supply and demand, and the proportion of resources such as orderly charging of electric vehicles, V2G and demand-side response will increase significantly. With a high share of solar generation and low electricity prices in the midday, pumped storage, storage batteries, electric vehicles and demand response loads all take advantage of low valley electricity prices to charge or use electricity; when electricity prices rise in the evening when peak usage occurs, they discharge into the system, increasing revenue while providing ancillary services.

Figure 19 Hourly power balance in China's power system for 2060 summer in the CNS2

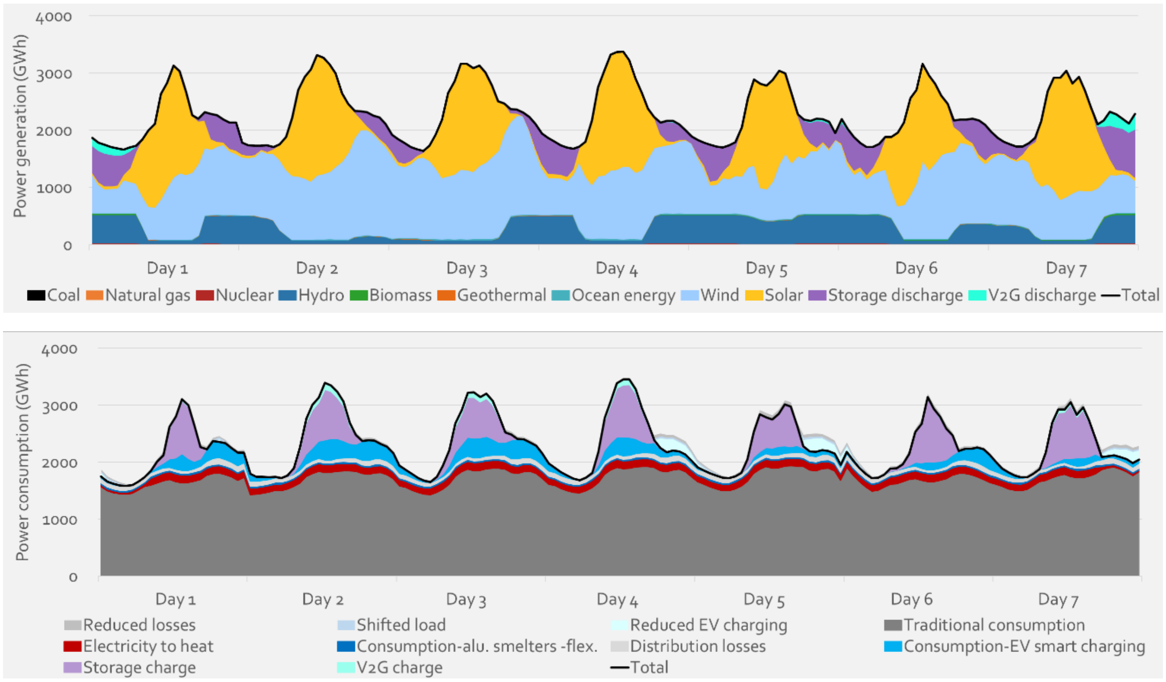
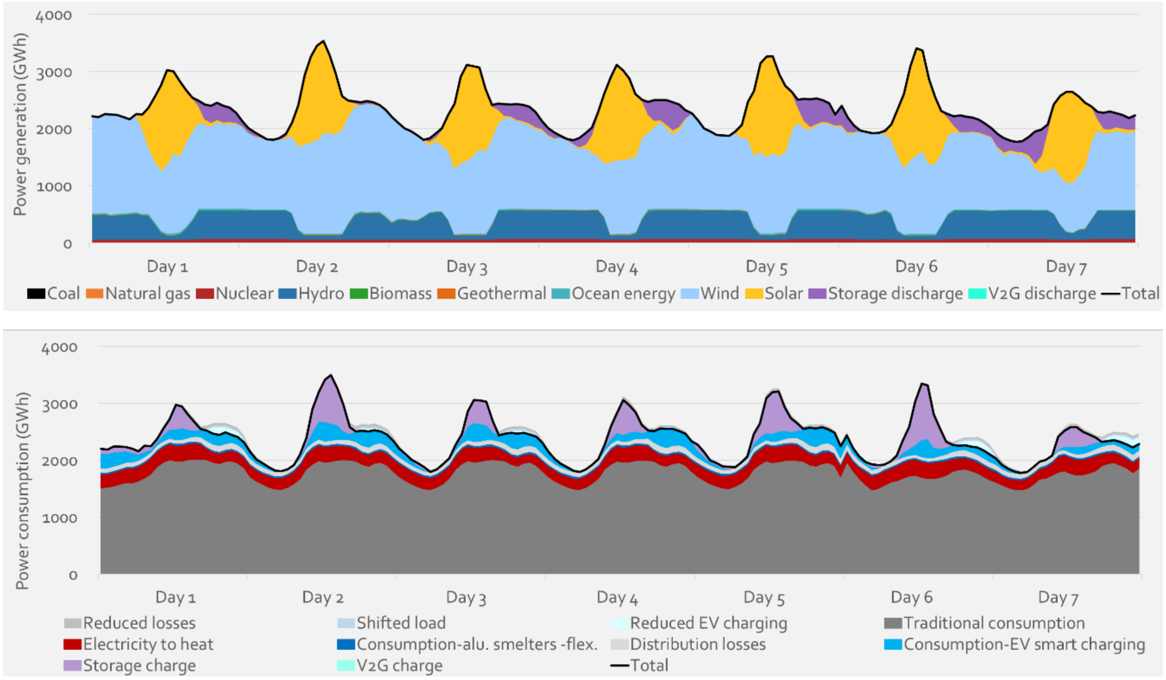


Figure 20 Hourly power balance in China's power system for 2060 winter in the CNS2



4.7 Market-based drivers are essential for the energy transformation

From a technical point of view, the energy transformation is feasible and economically viable, and it will fulfil the targets of carbon neutrality, energy security and affordable energy. However, to ensure the implementation, institutional barriers must be removed, and institutional drivers must be in place.

Among the market-based drivers, a functioning power market and an efficient carbon market are the most important. In general, wind power and solar power are already competitive with new fossil-fueled power plants today. Still, a combination of spot markets and long-term power purchase agreements is essential for the economic viability of individual projects. Dynamic pricing (time-of-use based) is crucial for the development of demand-side response and for investments in energy storage and power system flexibility. Separate markets for system services like ancillary services and system adequacy would be necessary when the share of variable energy production increases. For the power sector and the industry sector, a price on CO_2 emission is a strong incentive for the transformation, provided that the price is sufficiently high.

Barriers on the provincial level to the phase-down of coal and the deployment of renewable energy should be removed, and economic incentives for the provinces to encourage a rapid energy transformation should be in focus.

4.8 Wrap-up

The scenarios in the China Energy Transformation Outlooks illustrate, on a detailed level, how the targets for carbon peak and carbon neutrality can be realised.

Energy efficiency improvement on the demand side is needed to ensure that the pace of supply-side deployments can keep up and sustain economic growth.

Green energy supply – technological progress and cost reduction make wind and solar power able to provide clean energy in bulk, mainly through renewable electricity, and green heating will replace fossil-fuel heating.

Electrification will support switching away from fossil fuels in industry, transport and building sectors, in conjunction with the 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 sectors such as heavy transport, shipping, and aviation.

Sequestration of CO_2 creates the backstop or last resort option, by providing negative emissions through storing carbon in carbon sinks. Negative emissions can compensate for a modest level of emissions still in the system to ensure carbon neutrality.

Finally, drivers for transformational change are needed, including power markets, carbon markets, long-term planning, concrete innovation and implementation strategies and cooperation across stakeholders, locally, nationally and internationally.

In the CETO scenarios, with the deepening of the low-carbon transformation of the energy structure, the carbon dioxide emissions in China's energy sector will peak before 2030 and then gradually decline, among which CNS1 and CNS2 will decline more significantly. In the CNS1 scenario, net-zero carbon emissions are achieved around 2055; In the CNS2 scenario, net zero carbon emissions will be achieved before 2055, which will provide a strong guarantee for China's economic and social system to achieve carbon neutrality by 2060.

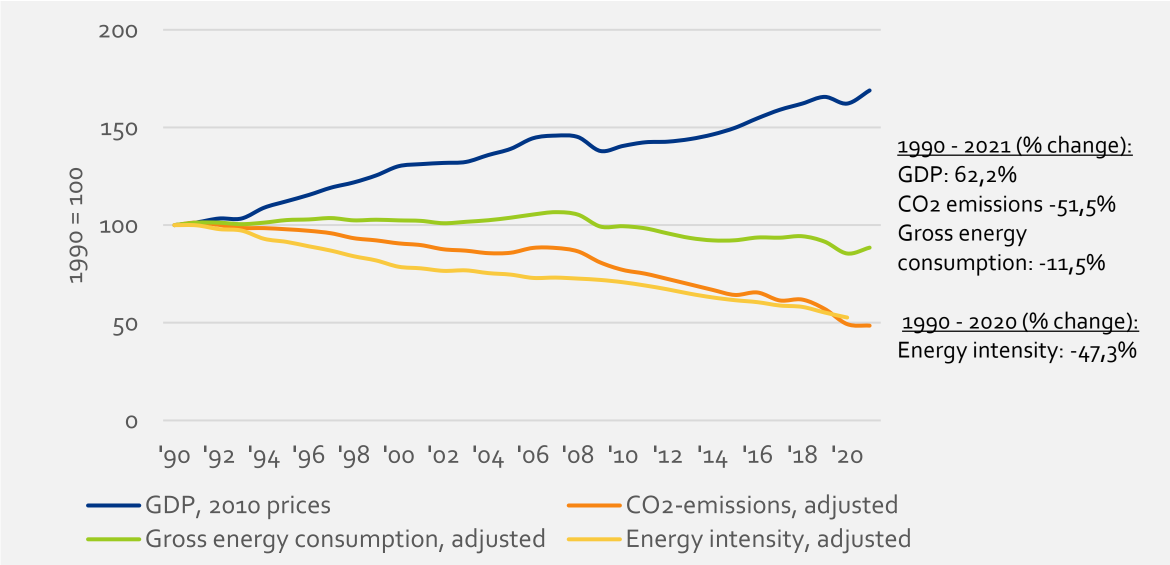
Chapter 5

Denmark’s climate policy status and framework

5 Denmark's climate policy status and framework

Over the course of four decades, Denmark has transitioned away from almost complete fossil fuel dependency to having a high level of overall renewable energy usage (43.1% of observed energy consumption as of 2021). Growing economic activity has coincided with decreasing energy intensity, increasing energy efficiency and declining CO_2 emissions, as Figure 21 shows.

Figure 21 Denmark's GDP, CO_2 emissions and gross energy consumption, 1990-2020



Source: Danish Energy Agency's Yearly Energy Statistics

Underlying this transformation is a long history of energy and climate policy agreements, which in most cases have been backed by a broad political base in the Danish parliament. This broad political support for energy and climate transformation has facilitated the establishment of institutional setups, policies and regulations that secure Denmark's energy and climate goals and commitments in both the mid- and long-term.

As early as 1990, the Danish Parliament approved "Energy 2000", which contained a CO_2 reduction target (the first in the world) towards 2005 and was followed by several new energy and climate agreements in the 2000s and 2010s. In 2020, the Danish Parliament passed the Climate Act, which entails a commitment to reducing greenhouse gas emissions (GHG) by 70 pct. by 2030 (relative to 1990) and to achieving climate neutrality by 2050 at the latest. These climate objectives are in line with the Paris Agreement, which pledged to limit a global temperature by 1.5 degrees Celsius.

Table 1 contains an overview of the Danish climate and energy targets and commitments.

Table 1 Overview of Denmark's national climate objectives, agreements, and international commitments in relation to climate change

Denmark's Climate Act	
Area of relevance	Description
10-year greenhouse gases (GHG) reduction goal	By 2030, Denmark's GHG emissions shall be 70% lower than in 1990
5-year indicative GHG reduction goal	By 2025, Denmark's GHG shall be 50-54% lower than in 1990
Net zero emissions	By 2050, Denmark will not emit more GHG than it absorbs
Selected sectoral agreements by members of the Danish parliament	
Area of relevance	Description
Energy	By 2030, Denmark's energy sector shall not rely anymore on coal, oil, and natural gas. Denmark has an ambition to quadruple its onshore renewable energy output from solar and onshore wind (production from these sources was 11,8 TWh in 2020). It has also been agreed to quintuple offshore wind capacity to 12.9 GW by 2030.
Reduction of GHG in Agriculture and Forestry	By 2030, the sectors will have reduced GHG emissions by 55-65% relative to 1990
Reduction of Co_2 emissions in road transportation	By 2030, road transportation will have reduced its emissions by 2.1 Mt Co2e (1 Mt Co2e by 2025). Ambition to have 1 million zero and low-emission vehicles (30% of fleet)
EU Fit for 55	
Area of relevance	Description
Sectors within the EU ETS	Concerned sectors will jointly reduce GHG emissions by 61% in 2030, relative to 2005
Renewable energy	EU countries will jointly achieve 40% of renewable energy in the overall energy mix
Energy efficiency	EU countries will jointly reduce final energy consumption by 36% in 2030 (relative to the 2007 EU Reference Scenario), which is equivalent to a 9% reduction relative to the EU Reference Scenario 2020.

Note: The EU Fit for 55 legislative package has entered the final stages of inter-institutional negotiation before final approval, after the EU Commission has adopted an official position which will form the basis of negotiation with the EU Parliament.

5.1 Status and projections on Denmark's climate effort

According to the latest Climate status report and projections from the Danish Energy Agency, by year-end 2020 Denmark had reduced its GHG emissions by 43% with respect to 1990.

In accordance with the Danish government's latest estimations presented in the Climate Programme 2022 – which includes all relevant policies adopted so far – the reduction effort is expected to reach 49.5% by 2025 and 63.6% by 2030. This leaves a reduction deficit of 0.5 – 4.5 percentage points relative to Denmark's goal of a 50-54% reduction by 2025, and of 6.4 percentage points, relative to Denmark's 70% reduction goal by 2030. Figure 22 presents an overview of Denmark's historic and projected emissions by sector.

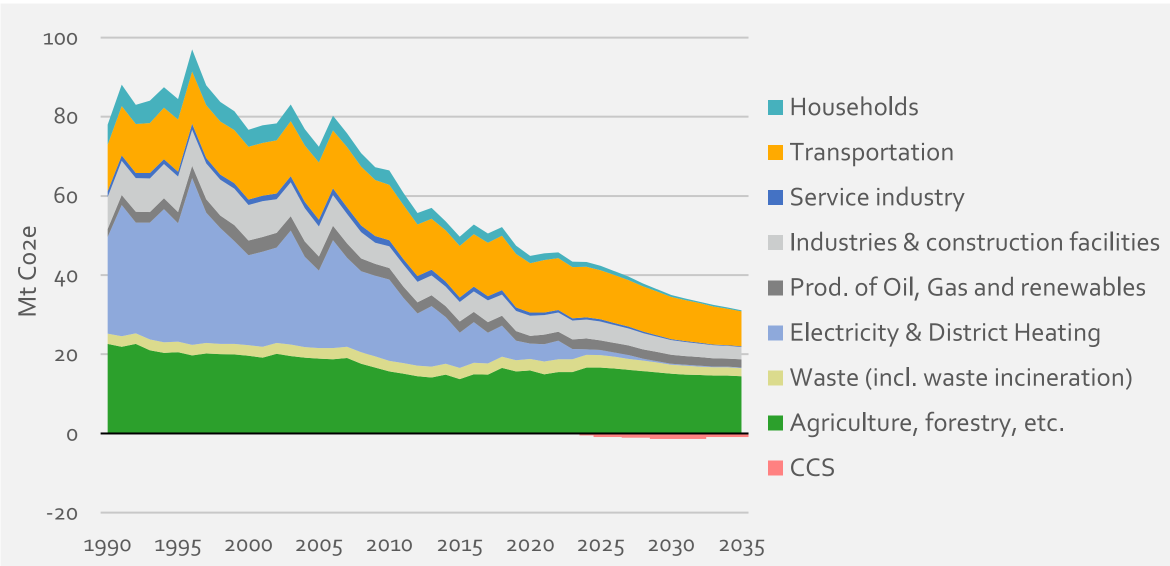
The Climate Programme includes recently agreed policies regarding CO_2 taxation, toll charges for truck transportation and further agreements on the expansion of renewable energy, including space heating. One notable characteristic of Denmark's present status on climate efforts is that emissions from electricity generation and district heating have fallen by 84% in the 1990-2020 period, leaving agriculture and transportation as the sectors that require most effort. Jointly, these two sectors accounted for 63% of all GHG emissions in 2020.

Agriculture, which is projected to emit 15.11 Mt Co_2e (and account for 43% of emissions) in 2030 without additional policies, is expected to reduce its emissions by 55-65% by 2030, in accordance with the parliamentary agreement on the matter. However, the largest share of the estimated reduction effort depends on the achievement of technological progress in areas such as brown bio-refining (pyrolysis), as it is currently challenging to limit agricultural emissions without significantly limiting production.

Another important area of effort for the success of Danish climate goals is road transportation, which accounts for approximately 26% of all emissions. Particularly, passenger car transportation is responsible for most transport-related emissions. Here, the success of the reduction effort is mostly placed on electrification with an ambition of 1 million low-emission vehicles by 2030. According to recent figures from Statistics Denmark, both Electric Vehicles (EVs), Plug-in Hybrid Electric Vehicles (PHEVs) and other low-emission vehicles are making strides, as 39,1% of new vehicles sold in the period October 2021-September 2022 were of this type. A ban on the sale of new gasoline- and diesel-fuelled vehicles still is not yet within reach, as this is currently outside the limits of EU legislation. However, there are proposals under discussion at the EU level that would allow a ban on fossil-fuelled vehicles by 2035.

One further significant aspect of the Danish reduction effort is the expected contribution of Carbon Capture and Storage (CCS), which is projected to capture 4% of emissions by 2030 and to start capturing emissions by 2025. This technology is particularly relevant for industrial, agricultural, and other processes such as waste-to-heat and waste-to-electricity, which may otherwise be hard to decarbonize.

Figure 22 1990-2035 Denmark's total emissions by sector



Source: Danish Energy Agency. Note: the latest statistical year in the figure is 2020 while the remaining years are projections

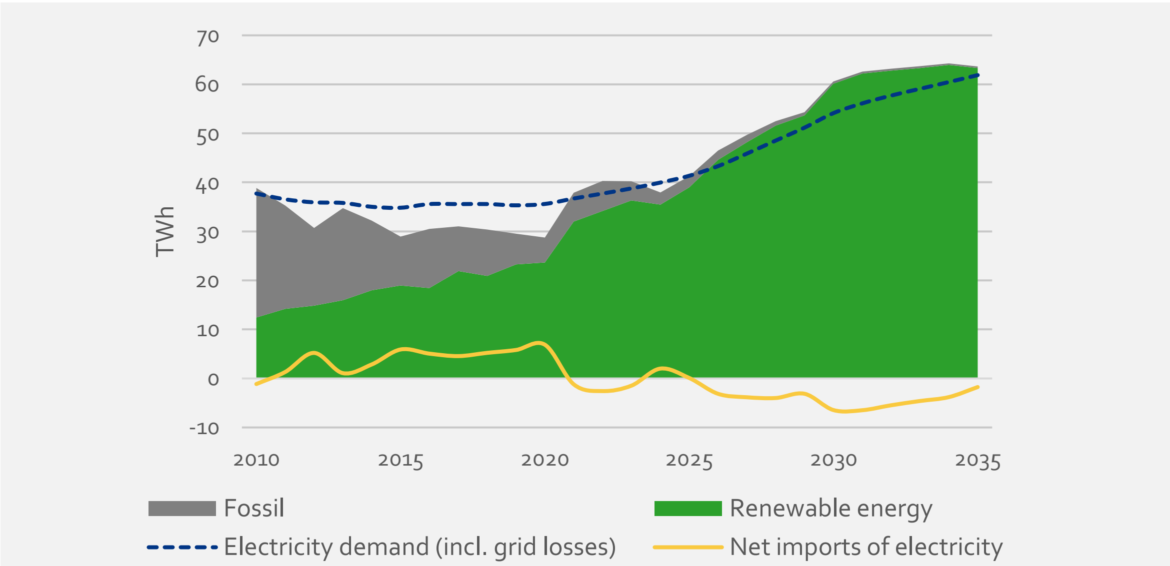
5.2 Denmark's way forward in the Green Transition is electrification

The most relevant characteristic of Denmark's Green Transition is its focus on electrification. As shown in Figure 23, production of electricity and heat have decarbonized almost entirely, creating a solid starting point for the direct electrification of transportation, heating, and potentially other industrial processes. Indirect electrification, through the production of synthetic fuels in Power-to-X processes such as electrolysis, is also expected to play an important role.

As Figure 23 shows, both variable renewable electricity production and consumption are set to increase, which projects Denmark as a net exporter of electricity to neighbouring countries through the cross-border Interconnectors.

In addition, the structure of demand is expected to change substantially as EVs, and heat pumps enter the system with a flexible consumption pattern. Classic consumption from households and businesses is expected to represent approximately one-half of the total by 2030, down from the 90% share that it represented in 2019. The commissioning of new large scale data centres is also expected to increase electricity demand, but because of their relatively constant consumption pattern these will add less flexibility. Furthermore, the electricity system is expected to be even more interconnected than it is at present, as offshore wind production facilitates the creation of international offshore wind hubs with Denmark's neighbours such as Germany, Belgium, and the Netherlands.

Figure 23 2010-2035 Electricity production, demand, and imports



Source: Danish Energy Agency

5.3 Climate Act

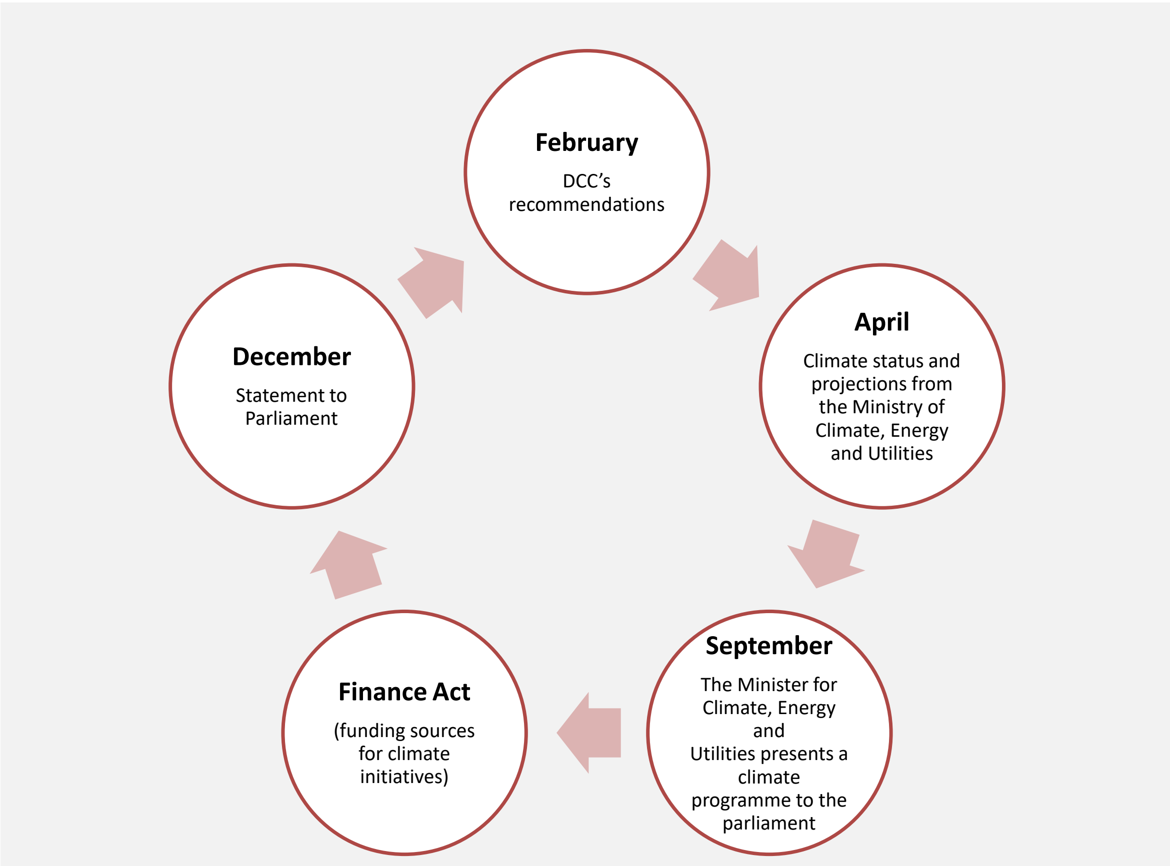
In 2020, the Danish parliament enacted the Climate Act which, besides setting legally binding targets and obligations (see Table 1), defines a governance framework to secure the long-term continuation of climate policies. The Climate Act assigns the Danish Council on Climate Change (DCCC) a role as an impartial expert body with an advisory and supervisory role on Danish climate policy:

- The DCCC advises the Ministry of Climate, Energy and Utilities on Denmark's climate effort including the establishment of goals and commitments
- The DCCC analyses potential means to transition to a low carbon society by 2050 and identifies possible measures to achieve GHG reductions, while accounting for technical feasibility and socio-economic benefits and costs
- Each year, the DCCC evaluates the government's climate policy and may suggest a review of the action plans presented by the Minister of Climate, Energy and Utilities, in case that these are deemed insufficient to achieve its goals
- The DCCC contributes to the public debate on climate change and engages with relevant stakeholders such as industry and labour market organizations, as well as representatives of civil society

The Climate Act requires the Minister of Climate, Energy and Utilities to establish a new 10-year climate goal every five years, which must be at least as ambitious as the previously established one. In addition, the Climate Act also establishes an annual climate policy cycle, in which:

- Every February, the DCCC presents recommendations and evaluates if the government is on track to achieve its binding targets and commitments
- Every April, the Ministry of Climate, Energy and Utilities presents a report on the status and projections of its climate policies. These should outline concrete policies to reduce emissions for all sectors: energy, housing, industry, transportation, energy efficiency, agriculture, and land use change and forestry.
- Every September, the Minister of Climate, Energy and Utilities presents its climate program and outlines climate initiatives as well as funding sources which are then included in the public financing act
- Every December, the parliament evaluates the initiatives presented at a public debate

Figure 24 Annual Climate Policy Cycle defined by the Climate Act



5.4 Green Taxation reform

Another important element of Danish climate policy is the recent approval of a broad taxation reform that facilitates the Green Transition in line with the 2030 and 2050 objectives. Although the Danish taxation system has throughout the years addressed negative environmental externalities derived from economic activity, the government identified the need for a more uniform taxation system that deals directly with CO_2 emissions.

Presently, the system consists of separate energy and CO_2 tax components on fuels and the EU ETS quota price applied in several industrial sectors. The effective tax on CO_2 emissions is considerably higher for fuels used in transportation and space heating than in industrial activities.

With the reform, by 2030 a tax will be applied to CO_2 emissions from industries both inside and outside the EU ETS quota system and a conversion of the existing energy taxes into a CO_2 tax on fossil fuels will be introduced in 2025. The new taxation system, which has an estimated impact of a 4.3 Mt CO_2e reduction, also accounts for a price floor mechanism that will be applied in case that the ETS price is low. Table 2 presents an overview of the tax rates to be applied.

Table 2 Overview of Denmark's Green Tax reform

Firm category	Tax rate (EUR/CO2) in 2030
Outside the EU ETS system	101
Within the EU ETS system	50
Involved in mineralogy processes (cement, glass, mineral wool, brick production, etc.)	17

Note: the tax rates are presented in EUR at an exchange rate of 1 EUR = 7,4381 DKK published by Denmark's National Bank on 11/10/2022.

Agriculture will not be subject to CO2 taxes as part of the agreement, but an expert group has been set up to examine how the sector's emissions are most appropriately regulated. The analysis and recommendations by the expert group will investigate policy options to reduce the agricultural sectors' non-energy related emissions, which could include a combination of CO2 taxes, state aid mechanisms and other regulatory initiatives.

5.5 Municipality level planning

Danish municipalities have considerable influence on many of the policies of the citizens living in a specific area and are the main decisionmakers within heat planning and the physical planning for onshore wind and solar plants. Because of this decentralized form of decision-making, Danish municipalities effectively have considerable impact on their CO_2 footprint. Planning at the municipality level coexists in Denmark with the broader national energy planning which – among other tasks – defines the overall framework to evaluate projects from a societal cost-benefit perspective.

As an example of planning at the municipality level, 95 out of the 98 Danish municipalities have established or are in the process of establishing binding agreements to design and formulate their own climate action plans, which live up to the requirements of the Paris Agreement.

5.6 Recent challenges

As a result of the economic re-activation after the COVID-19 pandemic, supply chain disruptions and the consequences of expansionary fiscal and monetary policies have resulted in strong inflationary pressures, which have been felt both in Denmark and elsewhere. In Denmark, the Consumer Price Index (CPI) escalated 8.9% in August 2022 – the highest year-on-year price rise since January 1983.

The recent geopolitical tensions experienced as a result of the Ukrainian conflict exacerbated the effects of rising inflation and have ultimately exposed European and Danish consumers to record-high prices, particularly within electricity and gas markets.

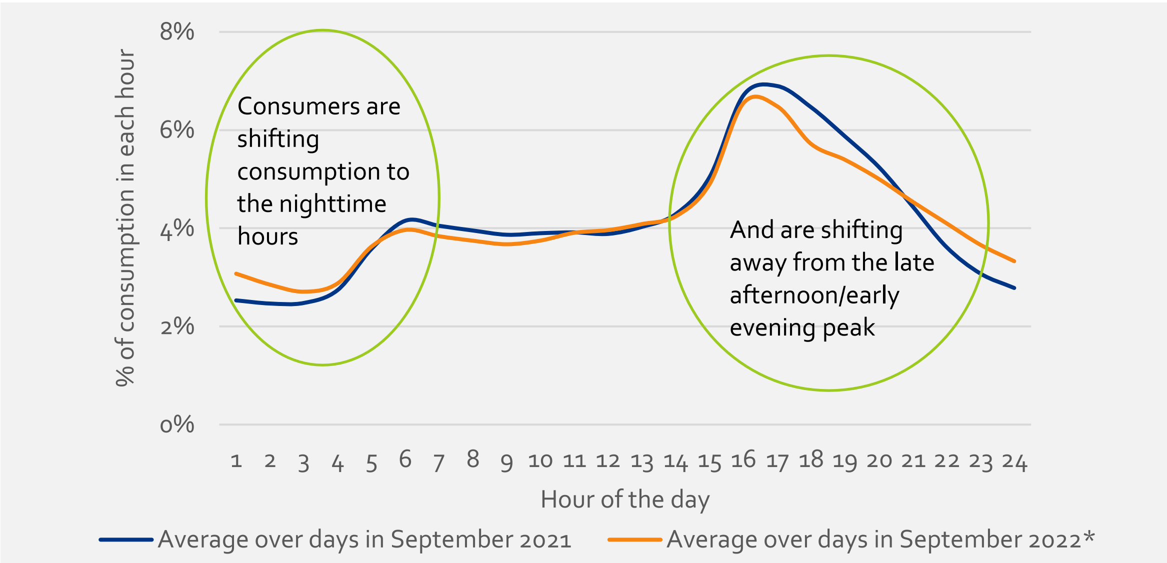
To address the issue, the Danish parliament has decided to give consumers the possibility to postpone part of their payment of energy bills over a longer period (5 years) and with a low interest rate. When the price of energy (gas, electricity, heat) exceeds a pre-established level (corresponding to the prices of Q4 2021), consumers can postpone the payment of the fraction of the bill that is above this threshold. The mechanism, which will last for 12 months, attempts a balance between consumer protection and the exposure to price signals, which support much needed flexibility and energy conservation measures. The Danish state will underwrite consumers' debt and will also provide liquidity to energy companies in the form of governmental loans in case these are necessary.

Electricity

The combination of high electricity prices together with the fact that all Danish households are metered and billed on an hourly basis, have increased consumer awareness, and have helped to incentivized flexible electricity consumption. The wholesale price of electricity tends to fluctuate between highs – when gas-powered producers set the price – and lows, when there is abundant wind and solar power production.

In a recent analysis, the Danish association for the energy industry, Green Power Denmark, has observed that high prices have motivated consumers to shift consumption away from the most expensive hours of the day and into the least expensive ones, proving that price signals work. A similar trend was observed by the Distribution System Operator (DSO) for the Greater Copenhagen region (Radius), which noted that on 5 October 2022 between 14:00 and 15:00 when wholesale prices were virtually zero, consumers increased consumption by 27% relative to the same hour in the previous two days.

Figure 25 Average hourly consumption of electricity (in %) during weekdays in September 2021 and September 2022



Source: Green Power Denmark (based on Energidataservice)

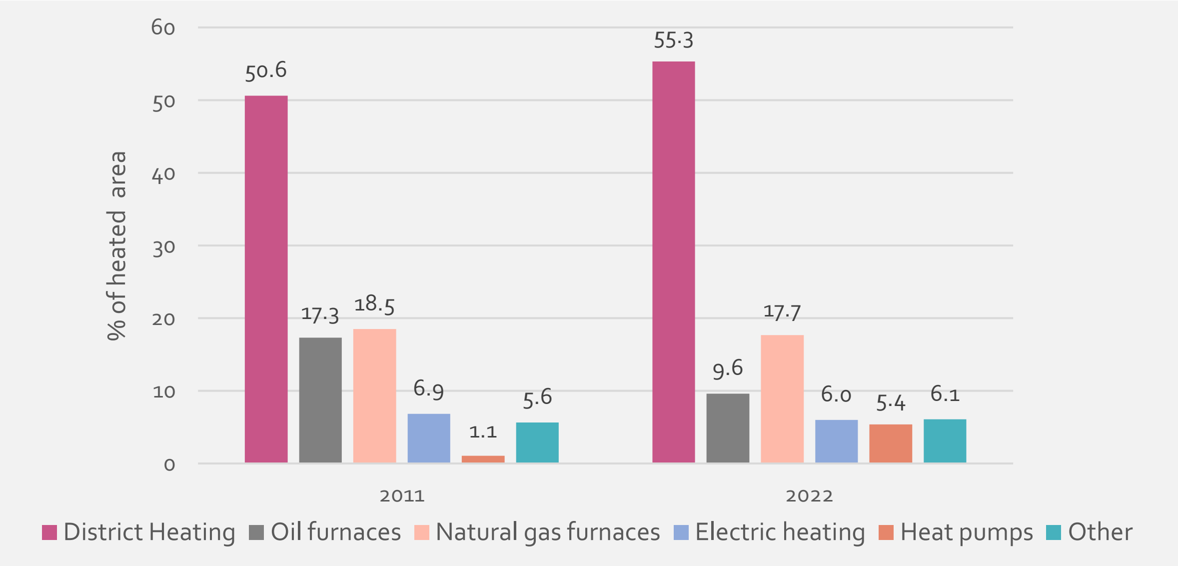
Another measure taken by the Danish government to address recent challenges and potential concerns for the insufficient availability of electricity supplies is the decision to postpone the closure of three fossil-fuelled power plants until 2024. The government has evaluated that the two forthcoming winter periods may be challenging due to the situation in the gas market and has therefore chosen to rely on domestic production to cover possible shortfalls in peak hours.

Gas

As a direct result of the Ukrainian conflict, the long-term contract between Denmark's Ørsted and Russia's Gazprom was terminated, leaving the Danish supplier in greater reliance on the European spot market to fulfil its commitments. A direct response from the Danish government, in cooperation with other EU Member States, has been to find joint alternatives to obtain the required supplies, and to increase the speed of the Green Transition.

On the domestic front, Denmark has declared a phase out of natural gas for space heating purposes by 2035 at the latest and has established a goal to become completely supplied with green gases by 2030. Presently, there are approximately 400.000 Danish homes that are heated with natural gas boilers and another 50.000 that are heated with petroleum boilers. The magnitude of the conversion challenge can be observed in Figure 26, which reveals that the second and third most common forms of space heating are respectively oil-fired and natural gas-fired furnaces. The figure also shows how district heating and individual heat pumps have increased their shares at the expense of oil and natural gas in the past 11 years.

Figure 26 Percentage of heated space by heating form (by 01/01/2022 and 01/01/2011)



Source: Statistics Denmark

Where it is technically and economically feasible, these homes will be offered the possibility to switch to district heating – which is supposed to take place by 2028 at the latest. The government estimates that approximately 30-50% of the gas-fired homes will switch to district heating, while another 20% will prefer an individual heating solution, such as a heat pump. Gas boilers will continue to exist in 2030 but will be supplied with green gases, mainly from digestion of mature and organic waste.

5.7 Energy security

The broader policy to ensure energy security in Denmark is closely related to the broader EU policy on the matter, which comprehends issues such as a cooperative framework to secure the availability of sufficient fuel supplies and a common strategy to ensure sufficient storages of natural gas and crude oil. Heightening geopolitical tensions recently motivated greater coordination among EU Member States to implement energy saving measures, the establishment of new energy partnerships with new suppliers and a common agreement to accelerate the clean energy transition.

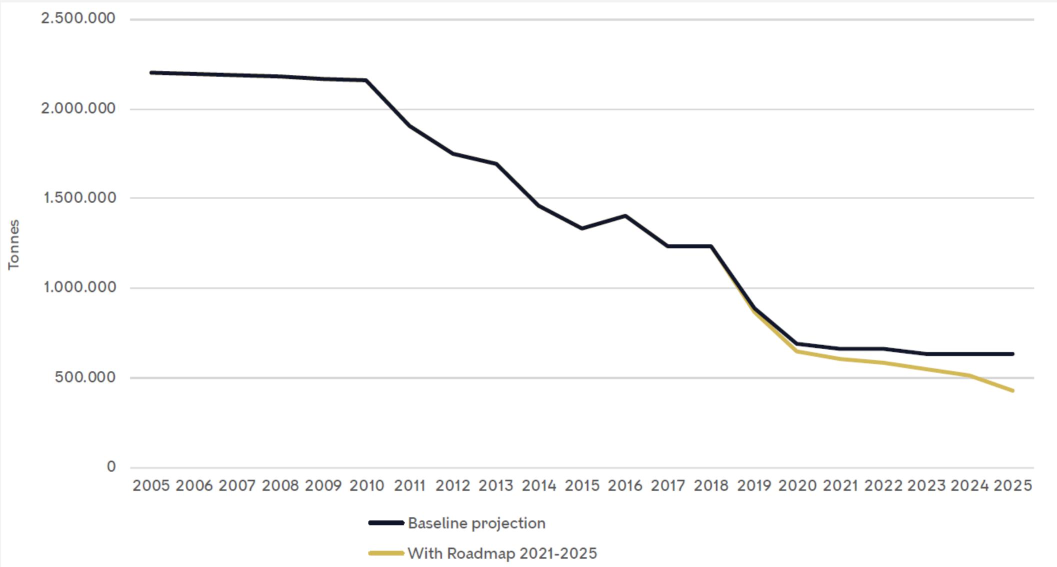
This common framework goes also across several institutional levels and touches on the broader security and defense of critical energy infrastructure. Inter-governmental cooperation and dialogue at the highest level becomes necessary, as the recent damages to Nord Stream 1 and 2 in the Baltic Sea, within the exclusive economic zones of Denmark and Sweden recently revealed.

A narrower but highly relevant perspective to energy security is the periodic evaluation and monitoring of system adequacy of the European electricity system, as outlined in the European Resource Adequacy Assessment (ERAA) framework. This periodic assessment determines system adequacy at the EU, country, and bidding zone levels. Regarding natural gas supplies to the European gas market, the EU legislative framework considers three crisis levels: an "early warning", an "alert level" and an "emergency" level.

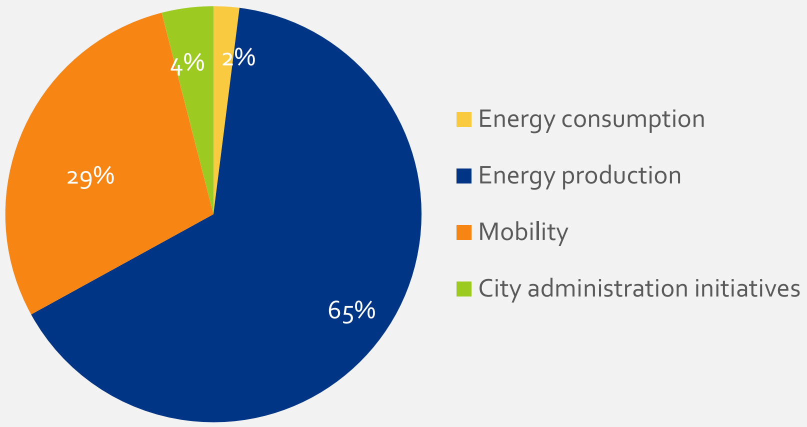
Box 8 Copenhagen is not giving up its carbon neutrality goal

Denmark is very proactive in addressing climate change, and Copenhagen, as the capital, has a special obligation to be a climate pioneer. Copenhagen formulated the CPH 2025 Climate Plan in 2012, proposing a goal of achieving carbon neutrality by 2025. It will be implemented in three steps (2012-2016, 2017-2020, 2021-2025), and each step is accompanied by a roadmap, proposing specific plans for that stage. The latest roadmap, CPH 2025 Climate Plan - Roadmap 2021-2025, was released in 2020.

Figure 27 2005-2025 Carbon emissions of Copenhagen



The CPH 2025 Climate Plan is based on four pillars: energy consumption, energy production, mobility with reduced emissions, and city administration initiative. Each pillar includes a package of action plans and initiatives, e.g., energy efficiency operations in different building types, electrification in public transport, switching its power and heat supply to renewable resources, eco-labelled products and services, etc. This Climate Plan is well implemented. The baseline for Copenhagen's carbon emissions is 2005, where Copenhagen emitted 2.3 million tonnes of CO_2. By 2018, carbon emissions were reduced by almost 1.2 million tonnes, primarily due to the decarbonisation of power-generation and district heating systems. Up to now, Copenhagen has reduced its CO_2 emissions by 80%– above the 70% target for this year.



It expects to reduce emissions by 80% through the efforts of the four pillars. The remaining emissions, especially in the transport area, were supposed to be neutralised by installing carbon capture and storage (CCS) technology at the local waste-to-energy plant, which contributes to negative emissions and P2X transport fuels.

Therefore, a decision has been made to put ARC (Amager Ressource Centre), a semi-public utility, in charge of establishing a full-scale plant for carbon capture. This plant will capture 500,000 tonnes of CO_2 annually and be fully capable of absorbing the remaining emissions of Copenhagen. This pilot was set to be ready by the summer of 2022, with the full-scale set-up deadline in 2025. But at the beginning of August 2022, the ARC announced it was ineligible for national CCS funding and could not build it as planned. Without such CCS capacity, Copenhagen must default on its carbon neutrality pledge in 2025.

But it doesn't mean Copenhagen will forever give up the carbon neutrality goal. As Sophie Hæstorp Andersen, the mayor of Copenhagen, recently said, "It's super unfortunate that we won't reach the goal in 2025. I'm very sad about it. But it doesn't mean we can't get there in 2026, 2027 or 2028. So, we still have hope that we can succeed." Once ARC gains access to the CCS funding, Copenhagen could quickly get back on track towards carbon neutrality.

Chapter 6

Case studies from the Danish Energy Transition

6 Case studies from the Danish Energy Transition

As part of its climate policy goals, Denmark is advancing several climate change mitigation initiatives with particular emphasis on the increase of renewable energy production and the electrification of society – both directly and indirectly. Transportation and heating are two areas that can be directly electrified, while industrial activities may require a more indirect approach, for example through Power-to-X solutions.

6.1 Energy Islands

Since the establishment of the world's first offshore windfarm (Vindeby, 1991), Denmark has been committed to advancing offshore wind technology and production. Between 2010 (0.9 GW) and 2022 (2.3 GW), the installed capacity of offshore wind has more than doubled. Based on a broad parliamentary agreement from 2020, Denmark decided to raise its ambitions much further and establish two energy islands, in the North Sea (up to 10 GW) and close to the island of Bornholm (3 GW) in the Baltic Sea.

Taking into consideration all the relevant parliamentary agreements and earmarking of funds, Denmark has the ambition to expand installed offshore wind capacity to 12.9 GW by 2030, which is a fivefold increase relative to the presently existing capacity.

The islands are planned to be a massive gathering of offshore wind generation capacity, which will serve as a node in the development of a future offshore transmission grid interconnecting the electricity systems of Denmark and neighbouring countries like the Netherlands and Germany.

Figure 28 The location of Denmark's energy islands

Source: The Danish Government

The islands represent a radical paradigm shift away from the radial interconnections approach of the present, in which offshore sites are connected to an onshore point of coupling. In the future, interconnected offshore wind farms will serve the dual purpose of supplying electricity to the local market and transmitting power across international interconnectors. An early-stage example of such hybrid infrastructure is the Kriegers Flak Combined Grid Solution, which interconnects the Kriegers Flak wind farm on Danish waters with the Baltic 1 and Baltic 2 windfarms on German waters.

Furthermore, the islands are expected to play an important role in the development of Power-to-X solutions, as related infrastructure is expected to be placed either directly on the islands or at onshore landing zones. Hydrogen is expected to be produced based on wind and solar power and then may be fed into the future European Hydrogen Backbone (EHB) infrastructure in which Denmark takes part or used directly for production of synthetic fuels.

6.2 CCUS and Power-to-X

The achievement of Denmark's climate goals and commitments relies to a certain extent on the progress of technologies that – although proven – are still at a pre-commercial phase. Two relevant examples are Carbon Capture Utilization and Storage (CCUS) and Power-to-X.

With respect to CCUS, the Danish Government has established a series of agreements which aim at supporting the emergence of a CCUS value chain in the country, with particular emphasis on biogenic sources. Throughout several legislative agreements, several relevant steps have been taken:

- Identifying storage locations and establishing the regulatory framework to store CO_2 in Denmark
- Initiating the competitive assignment of state aid over the course of 20 years to support the establishment of an initial CCCUS project, which is expected to realize CO_2 reduction in the order of 0.4 Mt Co_2e by 2026. So far, three projects have pre-qualified, and a final decision on the project to receive state aid is expected to be made by 1 January 2023.

According to recent estimates, CCUS has an estimated reduction potential of 1,4-6,5 Mt Co_2e by 2030.

Concerning Power-to-X, there is an established goal of 4-6 GW electrolyser capacity by 2030. Relative to fossil- and bio-fuel alternatives, this technology is however not yet competitive in market terms. Denmark has initiated a series of steps to develop a Power-to-X value chain:

- Competitive allocation of state aid for investments in Power-to-X and hydrogen projects. A bidding round to obtain state aid that supports industrialization and upscaling of Power-to-X applications is expected to take place during 2023.
- Regulatory reforms that improve the economic conditions for projects. For example, the introduction of geographically differentiated tariffs to incentivize optimal scaling decisions and flexible operation of electrolyzers
- Proposal to develop air transportation based on Power-to-X fuels.

6.3 Green Heating

One highly relevant area in which municipality level planning has historically played an important role is in the development of district heating. By trench length (30,000 km) coverage of the residential sector (65%) and by share of renewables used in the production of heat (69%), Denmark is a leading country in district heating. Energy efficiency and the coupling of sectors (through co-generation and the increasing use of large-scale heat pumps) are among the several benefits delivered by the Danish district heating sector.

Furthermore, district heating – which has an estimated potential of 73% of residential coverage by 2028 – is an important source of flexibility for the overall energy system, and thus facilitates the integration of renewables. In conjunction with co-generation, heat storages support flexible electricity production. Similarly, heat storages together with large scale heat pumps allow for flexible electricity consumption.

However, district heating is not the only form of green heating available. Individual heat pumps provide very high levels of energy efficiency (measured by the Coefficient of Performance – COP) and are another important source of flexibility for the energy system.

At a time when the Danish government has decided to phase out natural gas as a space heating fuel by 2035, the country is facilitating the conversion from fossil-fuelled furnaces to both district heating and individual heat pumps (see Figure 26). Among the main measures is the taxation reform adopted in June 2022, which includes a reduction of the electricity excise tax paid by all consumers, as well as more funding to expanding district heating and, from 2024, a reduction of the electricity tax on heat pumps.

6.4 Learnings from the Danish model

First, thanks to a series of early policies targeting environmental externalities and active support for wind power development and district heating, Denmark has achieved significant CO_2 reductions, steady economic growth and increasing energy efficiency over the past 40 years. This long-term transition, which has in fact decarbonised electricity and heat production, provides a solid basis for forward-looking and urgent work on climate change and supports Denmark's ambitious targets for the short (2025), medium (2030) and long term (2050). To support the achievement and monitoring of these goals, the Danish Climate Act sets out a governance framework with a system of checks and balances that ensures continuous monitoring of climate goals, commitments and plans. The government is obliged to act on its legally binding commitments, the Danish Climate Change Council has an advisory and monitoring role as an independent body, and Parliament has the final say on climate policy. So far, a combination of planning and market policies at local and national level has underpinned Denmark's transition. This combination of policies has contributed to a cost-effective green transition and will continue to be the overall approach for Denmark's existing energy sector. Another important policy element is the Danish government's proposed comprehensive tax reform, which will be implemented from 2030 onwards. This reform directly addresses CO_2 emissions and covers sectors of economic activity that are already covered by the EU ETS. In addition, the tax reform promotes the application of electrification and green heating solutions such as district heating and heat pumps.

Secondly, looking to the future, the most challenging sectors of the Danish economy to reduce emissions are road transport and agriculture, which will need to rely on a variety of technologies for transformational deployment. In the case of the former, the Danish government aims to have one million vehicles on the road that are electric and hybrid by 2030; for the latter, it has set a target of 55-65% emission reductions by 2030, according to a parliamentary agreement. In order to meet its national climate targets and international commitments, Denmark's focus will be on electrification - this includes both direct and indirect electrification. Transport and heating are the two main areas of direct electrification, while diversified conversion solutions for electricity using processes such as electrolysis will support the decarbonisation of other hard to abate sectors such as maritime and air transport. In its climate change mitigation strategy, Denmark relies on both existing proven technological solutions and those that have yet to be developed. As a flagship technology, Denmark will continue to promote offshore wind power with plans to build the world's first two energy islands. The two energy islands will concentrate on producing offshore wind power and will serve as the starting point for a grid offshore grid that will soon take shape, further connecting Denmark to neighbouring countries and to the electricity market within the EU. In addition to wind power, Denmark also relies on relatively immature technologies such as carbon capture, utilisation and storage (CCS) and diversified electricity conversion technologies. For both, the Danish government aims to accelerate its learning process by providing early support and state aid to projects with concrete, applicable and measurable climate change mitigation outcomes. Denmark, like many other countries, has recently faced serious inflationary challenges, which have been exacerbated by the crisis in Ukraine. Denmark's policy response has been to accelerate the green transition, while implementing consumer protection measures that still expose consumers to price signals that favour flexibility and energy efficiency. Overall energy security and, more specifically, ensuring security of supply in the electricity and gas sectors is a top priority for the Danish government. To this end, Denmark has recently postponed the decommissioning of two fossil fuel power plants in order to ensure that the Danish electricity system can weather the current energy crisis. The Danish government is committed to a high level of security of supply - a characteristic of the Danish system - while ensuring flexibility on both the supply and demand side.

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