WHEN TRUST MATTERS

ENERGY TRANSITION OUTLOOK CHINA 2024

A national forecast to 2050

FOREWORD

I am delighted to introduce this forecast on China's energy transition through to 2050. The publication of this report is one of the ways we are celebrating DNV's 160th anniversary year. For most of our long history we have had a business presence in China, which in fact started in 1888 with the posting of our first ship surveyor in Xiamen. The making of this report would not have been possible without the assistance of our colleagues in China, and also our network of external experts there, to whom we are very grateful.

No one who has visited China regularly over the last decade or so, as I have done, will have failed to notice the skies above the cities becoming clearer and the streets increasingly filled with electric cars and buses. These are the visible signs of a vast decarbonization effort taking place in China. From a position where, in 2023, China accounted for a third of the world's energy-related CO_2 emissions, by 2050 that share will have reduced to a fifth. In absolute terms, China's emissions will reduce by a staggering 70%. As we show in this Outlook, this is related mainly to the replacement of coal by renewables in the power mix and the electrification of end-use demand. In 2022, China was responsible for 35% of solar and 40% of wind power capacity additions globally. Moreover, its relative contribution of renewable capacity additions will continue all the way through to mid-century. The rollout of efficient, clean green electricity is not only a boon to the citizens of China but will profoundly impact the global push for clean energy.

In the next three decades, China will move up the rankings from 6th place currently to being the second most-electrified region globally. Expanding electrification, coupled with a policy-driven push for energy efficiency will see final energy demand peak in 2030 and fall by 20% by 2050, despite the rising prosperity of Chinese households. The structural economic shift towards a more automated manufacturing base and a larger service sector will also impact the nature and scale of energy demand.

Energy independence is the key motivation behind China's energy policy. We find that this is not wholly achieved by mid-century, when China will still be importing sizeable quantities of oil and gas. In our view, there is potential for China to accelerate its transition to reduce its reliance on these sources further and faster – and to bring China closer to net-zero emissions by 2050. That extra push relies to some degree on China's successful participation in global supply chains for critical inputs into renewable, storage, and transmission technologies.

We hope you find the insights contained in this report useful, and, as ever, we welcome any feedback you may have.

Remi Eriksen

Group president and CEO

DNV

HIGHLIGHTS

1 Energy independence is a key motivation for the Chinese energy transition, but is only partly achieved.

- Domestically-produced coal is replaced by domestically-produced renewables in the power sector
- Most oil and gas will still be imported, and while oil consumption halves by 2050 from the 2027 peak; natural gas consumption remains high through to 2050
- A faster transition to net zero in 2050 with less oil and gas use would significantly boost energy independence

2 China's energy use will peak by 2030 and reduce by 20% by 2050, driven by electrification and energy-efficiency improvements.

- In 2050, China will rival OECD Pacific as the most electrified world region, with electricity meeting 47% of final energy demand
- Energy intensity will decline by a third in 2035 and will halve in 2050 from today's levels, reaching 2.2 MJ/USD
- Demographic changes, including the population reducing by 100 million people, contribute to the decline in energy use

3 Already leading in renewable energy investments, China will more than quintuple renewable energy installations by 2050.

- China's power mix shifts from 30% renewables today to 55% by 2035, and 88% by 2050
- Leveraging its scale, experience, and export network advantages, China is poised to assist the rest of the world in meeting global renewable energy targets
- Nuclear installations double in absolute terms, but the share of nuclear in power production remains small, around 5% in 2050

4 Emissions in China are projected to peak by 2026, with a 30% reduction by 2040.

- China aims to reduce carbon intensity per unit of GDP by 65% from 2005 levels by 2030; we forecast a reduction of only 59% by then
- In the longer term, China is close to meeting its target of carbon neutrality by 2060, but will need to accelerate decarbonization of some sectors, e.g. manufacturing, to ensure net-zero by then
- China is responsible for a significant share of global CO_2 emissions – 33% currently and 22% in 2050, exerting a significant influence over levels of global warming and global climate impacts

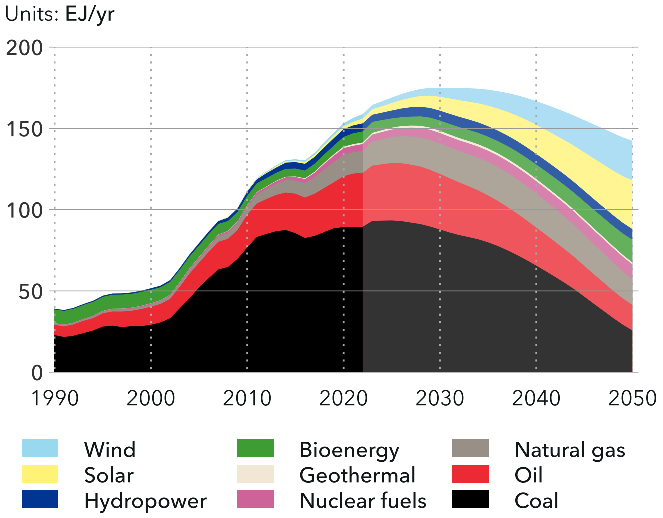
① Energy independence is a key motivation for the Chinese energy transition, but it is only partly achieved.

China's energy transition and carbon neutrality will be pursued in balance with other social and economic objectives. National energy security is an overarching strategic goal at the centre of Chinese policy. Energy independence is targeted through energy conservation, energy switching, and expansion of domestic energy supply capabilities and underpinned by nationally-controlled technology supply chains and, to the extent possible, domestic resource bases.

However, the ambition for energy autonomy is only partly achieved. The power sector is the first mover in replacing coal with domestically sourced renewable energy, and domestically produced coal will be sufficient for the remaining coal demand segments by 2050. Oil and gas usage will continue to rely on imports. Although oil consumption halves by 2050 from its 2027 peak, its use in petrochemicals and heavy transport (aviation and shipping) will linger and 84% of oil use will be met through imports. Natural gas consumption will remain high with 2050 consumption only 2% below 2022 levels and 58% being imported. The continued use of gas in power generation and buildings would be prime candidates for further replacement. A faster transition to net zero in 2050 where more oil and gas are replaced by domestically produced renewables or nuclear would significantly boost energy independence.

FIGURE 1

Primary energy supply by source



Historical data source: IEA (2023)

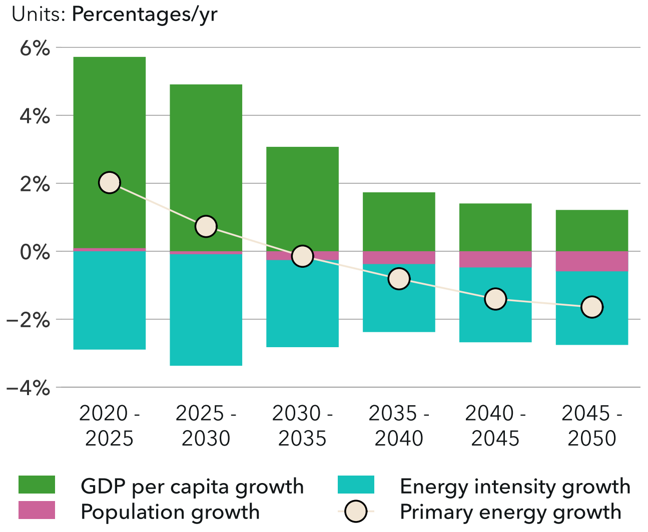
② China's energy use will peak by 2030 and reduce by 20% by 2050, driven by electrification and energy-efficiency improvements.

By 2030, China's energy usage is slated to peak, followed by a remarkable 20% reduction by 2050 as a result of electrification and efficiency initiatives. This decline is also enabled by demographic shifts, including a projected 100 million population decrease.

Of the 10 world regions in our forecast, China currently ranks as 6th in terms of electrification of demand, but it is projected to rise to 2nd place, comprising 47% of final energy demand by 2050, surpassing Europe and North America and trailing behind only OECD Pacific. Energy efficiency improvement is an important part of Chinese energy policy, and the targeted decline in energy intensity is evident: a 33% reduction, to 3.0 MJ/USD, is anticipated by 2035, falling to 2.2 MJ/USD by 2050. Legal frameworks like the *Energy Conservation Law* and *Renewable Energy Law* fortify these endeavours. Sectoral analyses reveal a notable efficiency surge in buildings, where efficiency more than doubles by 2050, propelled by the widespread adoption of air conditioners and heat pumps. The manufacturing sector exhibits gradual gains, while the transport sector anticipates a modest increase to 75% efficiency by 2050. Notably, China's holistic strategies extend beyond sectors, embracing insulation, recycling, and sustainable transportation logistics to curtail overall energy consumption.

FIGURE 2

Primary energy growth as a function of population, GDP/capita, and energy intensity improvements



③ China, already a leader in renewable energy investments, will more than quintuple renewable energy installations by 2050.

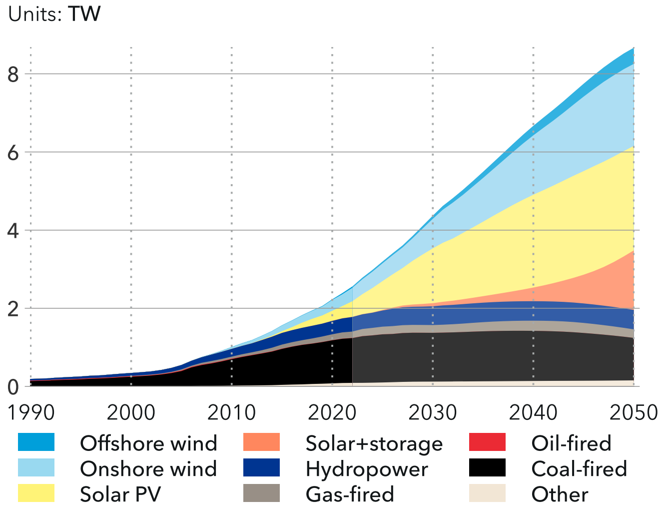
We expect a substantial transformation of China's power mix from fossil-dominated to a much cleaner one. The share of renewables in total electricity generation in China will increase from 30% today, to 55% by 2035, and 88% by 2050.

By mid-century, solar and wind each will be generating about 38% of electricity. For solar, more than a third of the installed capacity will be combined with storage, mainly batteries. For wind, 77% of power will be provided by onshore installations while 20% will be delivered by fixed offshore and 3% by floating offshore structures. Sustained cost reductions due to learning effects are the main driver behind the projected increase in solar and wind, with both technologies becoming the cheapest power sources in 2050. Of other non-fossil sources, nuclear installations will double in absolute terms, but will remain small in relative terms, producing only 5% of power in 2050.

Leveraging cost reductions and sustained global exports, China is poised to assist the rest of the world in meeting its renewable energy targets, exporting solar panels and most likely also wind turbines to most parts of the world.

FIGURE 3

Installed grid-connected capacity



Historical data source: IEA (2023), GlobalData (2023)

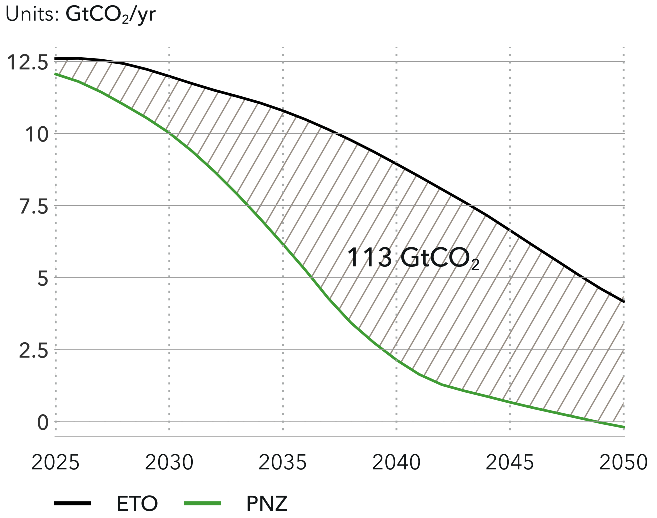
④ Emissions in China are projected to peak by 2026, followed by a 30% reduction by 2040.

In 2022, China contributed 33% of global energy and process-related CO_2 emissions, mainly from coal combustion. China's 2022 emissions hit a record high of around 12.1 $GtCO_2$. China aims to reduce carbon intensity per unit of GDP by 65% from 2005 levels by 2030; we forecast a reduction of only 59% by then. Nevertheless, DNV finds emissions likely to peak by 2026, well in line with the official target of peaking 'before 2030', thereafter gradually declining by two-thirds by 2050. By 2050, we project that China's emissions share will drop to 22% of the global total. In the longer term, China is close to meeting its target of carbon neutrality by 2060, but will need to accelerate decarbonization of some sectors, especially manufacturing, to ensure net-zero by then.

Given the weight of China's contribution to global emissions, the timing and depth of China's emissions reduction are of immense importance globally. The net-zero trajectory for China outlined in DNV's *Pathway to Net Zero* report (2023) shows that China's cumulative emissions could be 113 $GtCO_2$ lower than expected, significantly aiding global efforts to reach net zero by 2050.

FIGURE 4

ETO vs PNZ emissions



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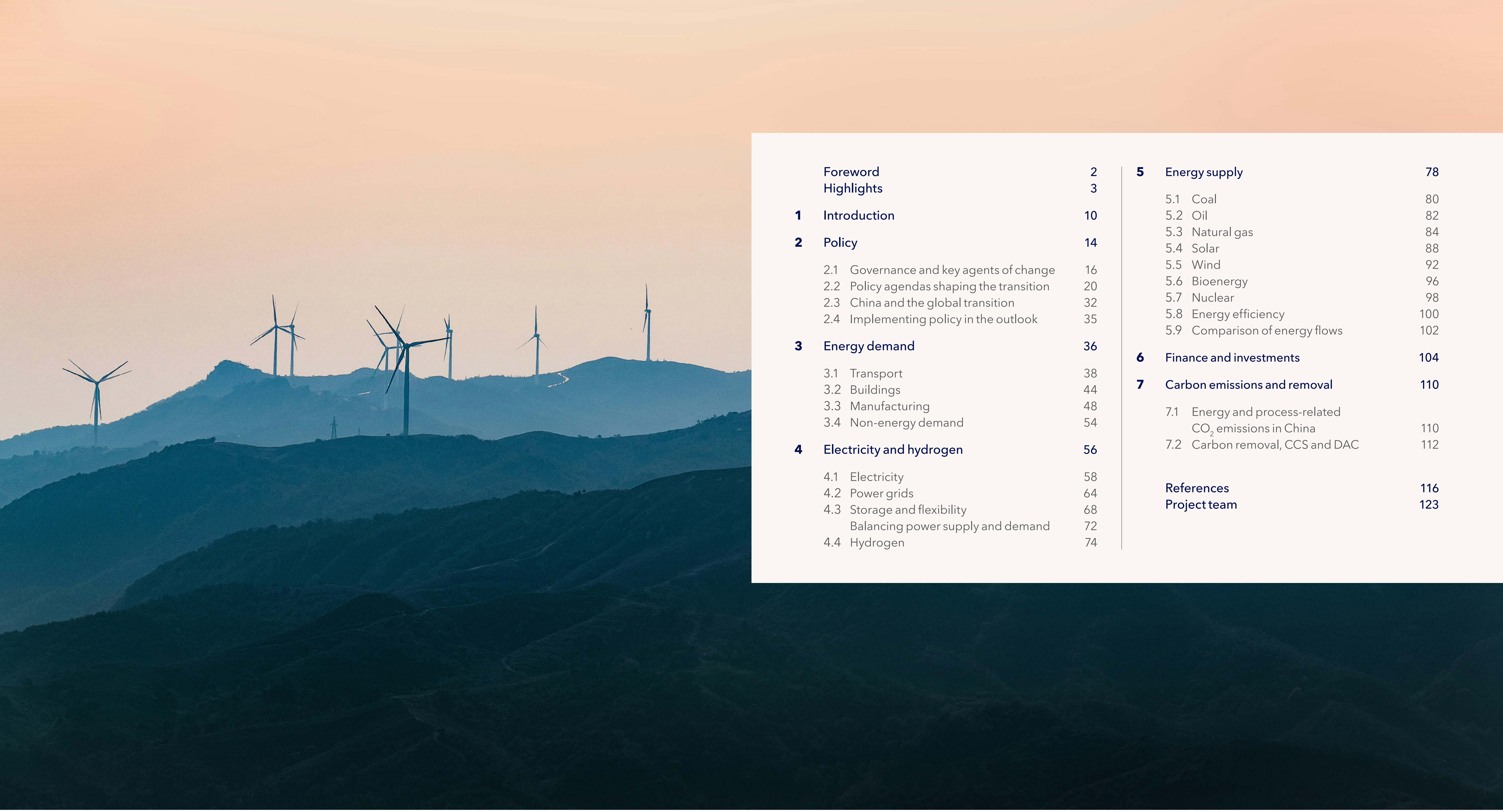

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KEY FIGURES

China

This region consists of Mainland China, Hong Kong, Macau, and Taiwan

	Population (Billion)	GDP* (USD trn) GDP/person (USD)	Energy Use (EJ) Energy Use/person (GJ)	Energy-related CO_2 emissions (GT) Energy-related CO_2 emissions/person (T)
2022	1.42	33 23,200	159 112	10.5 7.4
2050	1.34	67 50,400	142 106	3.3 2.5

*All GDP figures in the report are based on 2017 purchasing power parity and in 2022 international USD

INTRODUCTION

Today, China has 18% of the world's population, uses 26% of global primary energy, emits 33% of global energy-related CO_2, and is by far the leading installer of renewables. The energy transition in China is critical to its future and to the success of the global energy transition.

China currently finds itself in a transitional space in terms of its energy profile. It is by far the largest consumer of coal globally at over 50% of worldwide consumption, yet it is also by far the leading installer of renewable capacity. Over the next three decades, renewables will largely replace coal in China's power mix, helping to elevate it to the top rank of regions in terms of the non-fossil share of its power mix.

The central government sets China's policy direction and goals and has the power to ensure the party line is upheld, but relies heavily on lower levels of government and local officials for implementation. The stability of the government arguably removes some uncertainty from a forecasting perspective. However, there remains some uncertainty over the effectiveness of the future investment strategy of the state as it pivots from property and infrastructure spending towards support for higher value-adding manufacturing and consumption-led growth.

Population

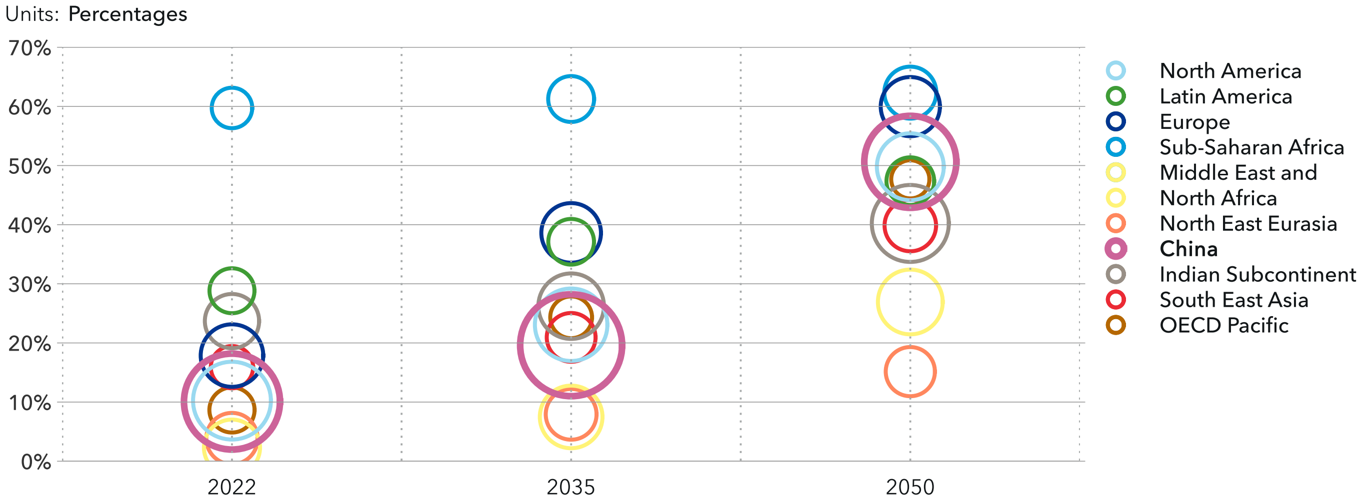
Most demographers, including the UN's Population Prospects, estimate China's population to have already peaked. The future rate of decline is somewhat uncertain, but fertility rates in recent years have remained very low despite policy countermeasures. With an ageing population, the energy needs of the country are shifting.

Importantly, the continued shrinking of the workforce in China introduces productivity challenges, particularly in manufacturing where an emphasis on added value and automation will gain primacy.

Two-thirds of China's population currently lives in cities, and while rural-urban migration is expected to slow, the proportion of individuals living in cities is expected to reach 80% in the next two decades. The larger urban population, coupled with smaller family sizes and an increased standard of living, will lead to an expanding demand for floor space and rising energy demand.

FIGURE 5

Share of renewables in primary energy consumption



Circle area is proportional to total primary energy consumption.

This will be tempered somewhat by the fact that urban high-rise buildings will use electricity, not the coal and biomass prevalent in more rural settings.

Growth

After decades with extraordinary real GDP growth of close to 10% per year on average, economic growth in China is widely expected to cool off. DNV's forecast has an average GDP growth in China of 2.5% per year through to 2050. A declining population and slowing migration to cities is one part of the root cause, but there are broader structural challenges. China faces a difficult era ahead of economic rebalancing towards consumption-driven growth, with a more targeted allocation of capital to less labour-intensive production, and the changing profile of exports made more difficult by continued protectionism. Growth rates will rely to a significant degree on China's domestic consumption and ability to raise productivity. However, China has a formidable capacity for innovation, not least, as we explore in this report, in green technologies. While growth rates will cool, we nevertheless expect per capita GDP to rise by more than 120% by mid-century.

Efficiency

China's programmatic focus on energy intensity – defined as the amount of primary energy used per GDP unit – has led to significant reductions, and these are expected to continue. The current rate of 4.5 MJ/USD is projected to decrease to 3.0 MJ/USD by 2035 and 2.2 MJ/USD by 2050. The drivers of energy efficiency gains are complex and intertwined – for example urbanization drives efficiencies in terms of more compact living and electrification, but also increases economic activity. Moreover, technological factors exert a strong influence, for example in transportation where technology shifts are leading to a rapid move to EVs and will later boost automation and sharing that will change and enhance the efficiency of the road transport subsector. Private car ownership in China will peak in the late 2030s while high-speed rail and especially aviation will grow, but the latter's energy demand will increase at a lower rate than passenger flight numbers due to cumulative operational and fuel efficiencies.

Energy security

China prioritizes national security and stability in its energy development strategy, emphasizing resilience and societal needs over rapid economic growth. The provinces have the same security and stability perspectives from their areas of jurisdiction, sometimes challenging the national priorities. Coal is predominantly domestically supplied, while 58% of natural gas and 76% of oil are currently imported. China leads the world by a considerable margin in its ability to develop and manufacture non-fossil energy technology competitively – nuclear, bioenergy, and renewables – and to that extent, clean technology does foster energy independence for China. However, it does remain dependent on imports of critical materials, including silver powder for PV panels, nickel, lithium, and cobalt for batteries, and uranium, and those supply chains will have to be nurtured.

> China prioritizes national security and stability in its energy development strategy.

China is constantly positioning itself towards the large oil and gas exporting nations in the Middle East and strengthening its energy cooperation with Russia. Nevertheless, China's long-term aim is to become energy independent, and domestically controlled coal will gradually be replaced with domestically controlled renewables and nuclear. Policy measures are focused on maintaining stability and meeting societal needs, such as ensuring sufficient and affordable energy for all, reducing local pollution, and maintaining jobs.

Short- and long term

The year 2023 was an outlier relative to China's energy and emissions trends since 2005 (Myllyvirta, 2024). With the rebound from COVID-19, energy demand grew at 5.7%, the first time in almost two decades that energy demand growth outstripped GDP growth. Moreover, the growth was particularly carbon intensive with coal consumption growing 4.4%, largely due to drought-impacted hydropower. However, it appears that subnational authorities and industries were also pursuing carbon-intensive projects in the 'window of opportunity' that remains ahead of the China's stated ambition to achieve peak emissions before 2030. In consequence, emissions rose by over 5% in 2023 and China's carbon intensity ticked up by 0.5%, leaving it off-track in terms off meeting its carbon intensity target of -18% set out by the *14th Five-year plan* (FYP 2021-2025).

An array of supporting targets, goals, and measures is in place in the present Five-year plan and the *15th FYP to 2030*. For the 2060 goal, the measures to achieve it are much less pronounced. Key to the achievement of both short- and long-term goals will be a continuation of the boom in clean energy installations. Planning in five-year cycles is likely to result in sufficient stepwise change to broadly achieve the 2060 goal but will likely not deliver the more ambitious trajectory needed for both the Chinese and global energy transition to deliver on the Paris Agreement goals.

ABOUT THIS REPORT

This ***Energy Transition Outlook*** (ETO) report details the energy future of China through to 2050. The analysis, the model framework behind it, the methodology, the assumptions, and hence also the results lean heavily on DNV's global forecast, *Energy Transition Outlook 2023* (DNV, 2023a). This is important, as the energy system in China represent a significant share of the global energy system, where technologies (learning rates, technology costs, technical solutions), economics (costs of materials, market prices, etc.), and policies are influenced by developments in other regions. The ETO model takes this into account by modelling China as a stand-alone region linked to the other regions globally; global and regional supply and demand balances are integrated into one single model.

Our approach

Unlike most energy forecasters, DNV does not develop scenarios. This is not because we know what the future will be like, but because not all futures are equally likely. We see a lot of merit in giving a best estimate. Hence, our analysis produces a single 'best-estimate forecast' of China's energy future. This forecast accounts for expected developments in policies, geopolitics, economics, technologies and associated costs, as well as some behavioural changes. DNV also publishes a net-zero 'back-cast', looking into what is needed globally and in each of the regions to achieve a future that limits global warming by 2100 to 1.5 degrees Celsius above the pre-industrial average. That *Pathway to Net Zero* was published in a separate report (DNV, 2023b), which also details the pathways of the 10 world regions in DNV's *Energy Transition Outlook* (ETO), including China.

Our model simulates the interactions over time of the energy consumers (mainly transport, buildings, and manufacturing) and all sources of supply. It encompasses the demand and supply of energy globally and the use and exchange of energy between and within the 10 world regions (see illustration below).

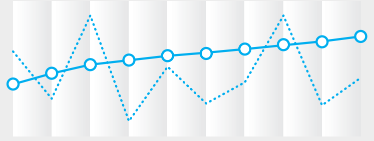
The analysis covers the period between 1990 and 2050, with changes unfolding on a multi-year scale that in some cases are fine-tuned to reflect hourly dynamics. We continually update the structure of our model and its input data. In this report, we do not repeat all the details on methodology and assumptions from the ETO 2023 report but refer readers to that open report for further details. China, with a 25% share of global energy demand, has led economic and technological developments in recent areas. Therefore, what happens to this region's energy system has enormous implications for the rest of the world, including through energy exports, financing, and technology innovation and breakthroughs with powerful impacts on cost learning rates.

Chapter guide

The policy landscape shaping China's transition is discussed in Chapter 2. In Chapter 3, we discuss the energy demand of the various demand sectors, and then in Chapters 4 and 5 we look at how the energy is supplied through energy carriers like electricity and hydrogen, and by all the primary energy sources – fossils, renewables, and nuclear. Chapter 6 describes the financial aspects of the transition, both for the region as a whole and for individual households. Finally, in Chapter 7, we quantify and discuss the emissions from the evolving energy system we forecast.

Our **best estimate**,
not the future we want

A single forecast, not scenarios



Long term dynamics,
not short-term imbalances

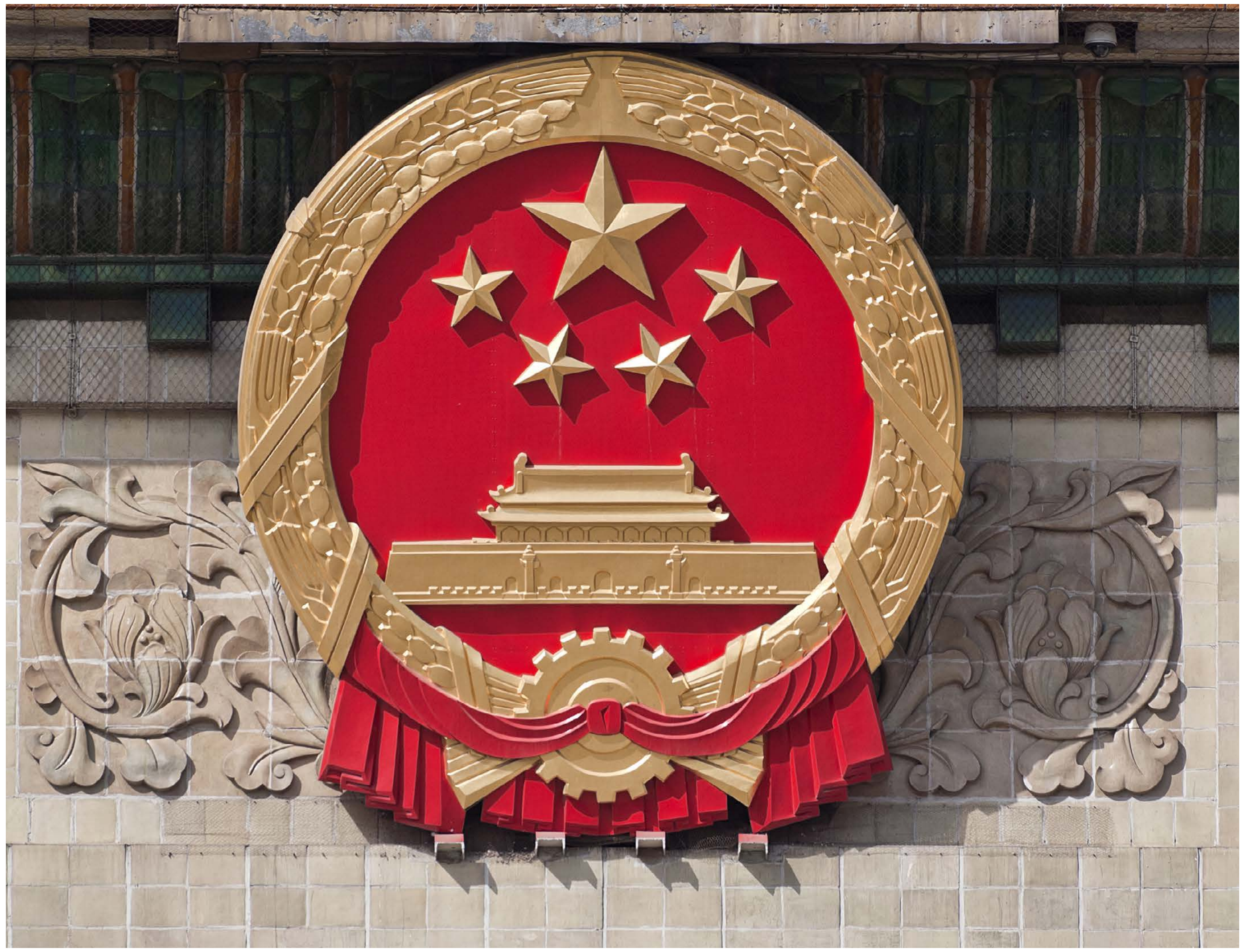
Continued development
of proven **technology**, not
uncertain breakthroughs

Main **policy** trends included;
caution on untested
commitments, e.g. NDCs, etc.

Behavioural changes: some
assumptions made, e.g. linked
to a changing environment

2 POLICY

Given China's share of emissions and the size of its economy, its energy policies matter fundamentally for global climate goals, global sustainability, and climate change diplomacy. As the world's largest coal user *and* producer of renewable energy, China's policy targeting these two fields will impact both the nature of China's energy transition and its ability to achieve carbon goals. The pendulum is now swinging towards renewables even though China's industrial economy is presently still mainly fuelled by coal. While a massive undertaking, China's climate goals are aligned with deep-seated domestic objectives and myriad policies are setting a large transformative shift into practical action.



CHAPTER HIGHLIGHTS

There are **carbon peak** (before 2030) and **carbon neutrality** (before 2060) objectives from China's central government but little clarity on the expected emissions peak level, which until now is mainly projected by research institutions. Government targets relate to emission intensity of GDP.

China has **clean energy at the centre of policy developments** for energy system decarbonization. However, deep fossil-fuel dependence results in only a minor change in near-term absolute fossil-fuel use. Emissions peak is forecast for 2026.

Policy and energy transformation plans have steadily materialized with targets and measures in the present *14th Five-year plan* (2021-2025) and some plans extending to 2035. The central government communicates continued commitment and support to the 2060 goal, although there are no specific targets on the emissions trajectory between 2030 and 2060. An absolute cap on emissions and binding reduction targets have yet to be set, but 2023 announcements on dual-carbon control signal a shift in this direction.

National security and stability top China's energy development strategy and policy priorities. Nuclear, hydro power, solar, and wind are synergetic with security objectives, yet before the emissions peak year, the central government also emphasize expansion of domestic coal and gas production for energy supply security reasons.

Power is the first-mover sector to transition away from fossil fuels and policies promoting renewables uptake increasingly rely on market-based measures.

Coal will be subject to regulatory command and control with policy aspiring to control coal consumption. However, capacity mechanisms for energy security reasons risk entrenching coal use, despite rapid expansion of renewable capacity.

Switching from coal in end-use sectors is the basis for **policies advancing electrification** and developing green hydrogen and its derivatives (synthetic fuels).

Policies for CCUS have focused on pilots and demonstrations as per China's NDC submission. CCUS scaling is expected to rely on carbon pricing, mandates and low-cost loans.

2.1 Governance and key agents of change

Policy plays a pivotal role in shaping China's energy future and the central government provides steadfast planning to direct energy system development towards a green transformation. China follows its own pragmatic pace in decarbonization, joining international initiatives when those align with domestic plans.

Nationwide holistic planning and innovation capacity
A nationwide Five-year plan (FYP) framework dominates governance. FYPs are manifestos for how the central government wants to steer the country and have been issued since the 1950s. FYPs are blueprints providing overall objectives and goals related to social and economic development and industrial planning in key sectors and regions. In October 2020, the central government formulated its recommendations for the *14th Five-year plan* (2021-2025). Unlike past plans, this one outlines long-range objectives through to 2035 (Government of China, 2021). The plan period sets the basis for the second centenary goal of building a modern socialist country by 2049 – the year when the People's Republic of China marks its 100th anniversary.

FYPs have a hierarchy where national plans are translated into region- and sector-specific FYPs at the ministerial, provincial, and municipal levels under the central government's guidance. Economic and social goals are expressed in both qualitative and quantitative terms and supported with sector- or area-specific FYPs with targets and allocated measurable contributions from governments at lower levels (e.g. the government's mandatory target of 10% reduction of SO_2 in the *11th Five-year plan on Environmental Protection* (2006-2010) and resultant implementation of desulfurization projects for coal-fired power plants).

Banks, research funding agencies, universities, and public research institutes are expected to align priorities with the FYPs. In other words, China's top-down and rules-based approach can concentrate resources on desired objectives.

Successive FYPs have been accompanied by persistent R&D support and favourable funding arrangements to cleantech areas and prioritized industry development. Its economic policy arguably resembles a mission-oriented approach to grand challenges (Mazzucato, 2017) with a clear future direction for the transformative and structural changes in the economy it is aiming for.

Local and regional implementation
Although China's climate and energy policy formulation is centralized, provincial and local governments are the key agents in policy implementation. China seeks to overcome an implementation gap with a target responsibility system through which key climate and energy targets are allocated to individual provinces, with provincial leaders responsible for fulfilling them. Since 2014, officials' performance ratings – a key criterion for promotions – started to include the implementation of climate goals (Liu et al., 2023). Local officials have less discretion to ignore environmental regulations in pursuit of GDP growth. However, from a regional perspective, there is vast disparity in resource endowments, economic development, and technology capacity (Lou et al., 2022). There are also conflicts of interest, such as the prospect of social costs from loss of fossil industry and jobs in coal mining, washing, and coal power (Zhang et al., 2021).

State-owned enterprises captaining the transition
State-owned enterprises (SOEs) play a key role in meeting the basic needs of the country and are the lead responders to polices at all levels. They dominate the energy sector and are the main clean energy investors and major energy producers, and consequently the main contributors to CO_2 emissions. As major energy consumers, they also help commercialization of private investments by being offtakers of clean energy (e.g. through requirements for green power consumption).

SOEs are instruments to serve national strategic goals. They carry a lot of political mandates oriented towards decarbonization, follow policies to adjust their energy production and consumption structures, and meet emission reduction targets. SOEs also take the lead on innovation, carrying long-term strategic projects with a 20- to 30-year timeframe that are non-commercial in the near term. They have a key responsibility in progressing technology development (e.g. to evolve hydrogen energy and carbon capture, utilization, and storage) through larger budgets for basic research and piloting. China Huaneng as an example, responsible for about 10% of China's total power generation, has increased its R&D input 40% annually in recent years. In alignment with 2021 requirements set by the State-owned Assets Supervision and Administration Commission of the State Council, Huaneng's share of non-fossil installed capacity is scheduled to reach more than 50% by 2025. By 2035, it aims for 75%, focusing on non-hydro renewable energy, hydropower, and nuclear. Most SOEs have set targets in line with the national target of peak carbon by 2030 or are even more ambitious. 20 of the 97 central SOEs have established clear roadmaps and pathways geared towards reaching the 2060 carbon neutrality goals (Zhang et al., 2023).

Although SOEs gain more R&D funding and preferential support as government policy directs energy-industrial development, private enterprises also strategically align and enjoy the tailwind of government policy, such as gaining support from local governments and having certainty around low-carbon opportunities (demand) in a large home market that has targets and fiscal frameworks to incentivize uptake. In fact, private enterprises lead in low-carbon manufacturing and play a critical role in China's renewable energy sectors such as solar, wind, and EV companies (Sheng, 2020).

Near- and long-term goals
While China has many agendas that shape the transition (Section 2.2), governance is progressively focused on unleashing changes in China's economy and energy structure required by the dual-carbon goals announced by President Xi Jinping in 2020. China officially submitted its mid-century, long-term low GHG emission development strategy and an updated National Determined Contribution (NDC) in October 2021, pledging to reach carbon neutrality before 2060 and peaking CO_2 emissions before 2030 (Table 2.1on the next page).

At COP28, Xie Zhenhua, China's special envoy for climate change, revealed that China's government will put forward its NDC to the Paris Agreement by 2025 with new targets and new measures for 2030 and 2035 (ChinaNews, 2023).

With ambitious goals, there is a wide range of increasingly dense climate and energy-related policy documents. Table 2.2 on the next page highlights a selection of key targets.

TABLE 2.1

China's commitments to the Paris Agreement

2030	2060
– Peak CO_2 emissions before 2030 – Reduce carbon intensity (CO_2/unit of GDP) to 65% below 2005 levels – Increase the share of non-fossil fuels in primary energy consumption to around 25%	– Achieve carbon neutrality before 2060

Source: UNFCCC (2021a)

TABLE 2.2

A non-exhaustive list of transition targets announced in China's *14th Five-year plan, Guidance*[1], *Action Plan*[2], and to the UNFCCC[3,4]

Economy-wide	Target
Energy intensity	– By 2025, decrease energy consumption/unit GDP by 13.5% (binding, versus 2020 levels)
Carbon intensity	– By 2025, decrease CO_2 emissions/unit of GDP by 18% (binding, versus 2020 levels) – By 2030, decrease 65% (versus 2005 levels)
Supply transition	**Target**
Non-fossil sources	– Increase the share in power generation to about 39% in 2025 and more than 50% by 2030 – Increase the share in total, primary energy consumption to about 20% by 2025 (at around 16% in 2020); about 25% by 2030; over 80% by 2060
Renewables	– 18% share of power consumption from non-hydro renewables by 2025 – 33% of power consumption from all renewables by 2025 – 1,200 GW wind and solar generation capacity by 2030 – About 40 GW of new hydro power capacity to be installed in both 14th and 15th FYP periods
Fossil sources	– Limit the increase in coal consumption over the 14th FYP period – Phase down of coal in the 15th FYP period – Maintain steady oil production (from its 2021 level) – Increase natural gas production (aim for 11% increase from 2021 levels)
Demand transition	**Target**
Electrification rate	– About 30% electricity in final energy consumption by 2025

1. CCP and State Council (2021), 2. State Council (2021a), 3. UNFCCC (2021a), 4. UNFCCC (2021b)

2.2 Policy agendas shaping the transition

Domestic economic resilience, technological self-reliance, stability, and security are the overriding Chinese policy objectives that will be balanced in the transition.

Self-reliance and development are the overriding policy priorities

A reliable energy supply that is affordable and meets basic needs tops China's energy development strategy and is essential to sustain resilience and security objectives. While domestic coal usage aligns with these objectives, it runs counter to decarbonization priorities. Overall, there is synergy between policies supporting non-fossil energy, cutting reliance on fossil-fuel imports, and advancing cleantech industries as an engine of future growth.

Economic development in the *14th Five-year plan* (2021-2025) has an indicative target, formulating GDP growth to be kept 'within a reasonable interval' given circumstances. The formulation reflects uncertainty from a more volatile geopolitical and post-COVID-19 global economic environment and provides political flexibility to pursue other targets, such as environmental goals and supporting a shift to high-quality production. Nevertheless, economic growth is a prominent policy priority embedded in China's 2035 vision of long-range objectives, which includes President Xi's aim to double the size of the economy by 2035 (Xinhua, 2020).

The central government wants to maintain the GDP share from manufacturing but targets adjustment towards high-quality production, pivoting from industry and investment spending (e.g. infrastructure, real estate) to a rising share in medium- and high-tech products and consumption-led growth in consumer goods and services. This shift, to the degree it is successful, will decrease demand for heavy industrial goods and help adjust manufacturing from high- to low-energy intensity. Industrial capabilities and manufacturing that have environmental advantages and low-carbon development as a strategic direction are enjoying favourable government policy. China sees decarbonization and clean energy industries as the future growth engine.

Domestically-controlled supply chains sustained by technological self-sufficiency, innovation, and education for talent have long been at the heart of China's modernization. Policy aims to boost economic autonomy and domestic economic resilience to market dynamics and trade tensions. China's dominance in cleantech did not come into being in a short period of time; it is the result of sustained investments in R&D and manufacturing. Several decades ago, then-leader Deng Xiaoping reportedly made the statement 'The Middle East has oil, and China has rare earths'. To follow up on this statement, China's *863 Programme* launched in 1986 to stimulate the development of 'advanced' technologies. The programme identified the role of strategic metals, materials, and rare earth elements for China's *High-Tech Development Plan* and to render China independent of foreign technologies. In 1997, the *863 Programme* was replaced by the *973 Programme*, also known as the *National Basic Research Programme*, to achieve technology and strategic advantages, especially in the minerals industry.

China sees decarbonization and clean energy industries as the future growth engine.

China currently has a stronghold on mining and processing of strategic minerals and rare earth elements critical for energy technologies (e.g. batteries, solar panels, wind turbines, and electrolysers) and favourable to industrial positioning in technologies for decarbonization. However, China still relies heavily on overseas critical minerals – such as nickel, cobalt, and copper – which are essential for new energy, and is making overseas metals and mining investments to secure the same (GFDC, 2023). The push for self-reliance is similarly behind the recently reported breakthrough (Levi, 2023) from the Chinese Semiconductor Manufacturing International Corporation (SMIC) and Huawei, which may be an important step in rendering China independent of foreign suppliers.

Dual circulation enshrines the ambition to be self-sufficient together with fully controlled supply chains. While international circulation and pursuing an export-led growth strategy has been a dominant source of revenue, the central government, as elaborated in the *14th Five-year plan*, aims to substantially bolster the consumption share of GDP. China's domestic consumption and market demand for services and Chinese-manufactured products (domestic circulation) will become a bigger engine of future economic growth, driven by a lower disparity between urban and rural living standards. Domestic and overseas markets will reinforce each other, with the domestic market as the mainstay. Nonetheless, as China's economy is slowing down after years of high growth, it seems that its economy has yet to reach a plateau in which consumer demand sufficiently buffers volatilities in China's export markets. The economic performance in 2023 appears to support this point.

Energy security is the basis for renewables promotion but also nuclear and coal expansions. China's long-term aim is to be energy independent, and the switch to renewables will make China less reliant on imported energy over the coming decades. In the near term, the energy transition will advance, but not at the expense of supply security. In fact, the *14th Five-year plan* named coal as 'the backstop of supply security'. Recent insufficient hydropower output, scorching summer temperatures driving an increase in electricity demand, and intensifying regional weather extremes make most parts of China susceptible to power shortages (Xia, 2023a). With looming power shortages, the government recognizes thermal power and coal as the guarantor of supply, balance, and flexibility, albeit with low coal-plant utilization. While energy security is the basis for renewable energy promotion to keep resources domestic, non-fossil sources will replace fossil sources only gradually. Recently policy also signals ambitions to expand coal usage to replace imported oil and gas (over 70% and 40% imports in primary energy supply in 2022, respectively) through construction of coal-to-oil/gas strategic bases (CCP and State Council, 2022). We believe this will make a modest contribution compared to overall oil use. Furthermore, we do not expect energy security to reverse the long-standing coal-to-gas/electricity switching policy that is rooted in air pollution concerns.

China's push for self-reliance and willingness to prioritize domestic energy resources is reflected in our forecast. Due to energy security reasons, various policies – ranging from capacity mechanisms for coal-fired power plants to guaranteed prices for solar PV and onshore wind – incentivize power technologies such as variable renewables, coal, and nuclear and de-incentivize gas-fired power plants, in the range of 5% to 20% of their cost. Looking ahead, decarbonization efforts will likely create new dependencies, such as import of ammonia, which is discussed in more detail in Chapter 4.

Strengthening environmental protection at home

Rapid economic growth has had serious impact on China's environment; air pollution, water availability and quality, soil loss, and biodiversity are among the main challenges. To address environmental degradation, the concept of 'ecological civilization' has taken root in China's effort to integrate environmental goals with human-economic activities. This concept has links to Chinese Taoist philosophy (Wei et al., 2021), and has environmental management, ecological restoration, and green development as its guiding principles to reconcile economic development and environmental protection.

'Ecological civilization' first appeared in policy documents at the 17th Congress of the Communist Party of China in 2007. Since 2012, President Xi Jinping has elevated the concept's maturation and practice, incorporating environmentalism into the logic of the Communist Party for a new development philosophy that rejuvenates economic sectors and realigns China's values with sustainable development goals. In 2018, the concept was embedded in China's constitution.

This concept has become a cornerstone of China's national development strategy for a new era that emphasizes economic development with 'quality over quantity' and reversing degradation of air, water, and soil harmed by rapid industrialization and urbanization. Pollution prevention and action plans have advanced in these areas (air, water, soil) in 2013, 2015, and 2016, respectively. Additional measures and targets were adopted for 2020 and 2030. China also played a crucial role in facilitating the *Kunming-Montreal Global Biodiversity Framework* (KMGBF) concluded at the Convention on Biological Diversity, COP15 in December 2022 as a step-change in biodiversity conservation and stopping biodiversity loss.

Policy to further the agenda

The 2010 *China National Biodiversity Conservation Strategy and Action Plan (2011-2030)* has guided plans and programmes on biodiversity conservation, but it has faced challenges from accelerated urbanization and industrialization, that increase pressures on water resources, habitats and ecosystems. January (2024), China issued its *National Biodiversity Conservation Strategy and Action Plan* (2023-2030) to align with goals and targets of the KMGBF.

Focusing on air pollution which saw significant peaking in 2013 and 2014, China declared a 'war against pollution' and expanded policies to tackle pollutant concentrations. The *Air Pollution Prevention and Control Action Plan* (APPCAP, 2013) established a multi-pollutant abatement plan by setting prohibitions on transportation and coal-burning entities such as in industry, power, and residential heating.

The new 2018-2020 *Three-year Action Plan for Winning the Blue-Sky War* deepened measures and established a stronger link between managing air pollution and climate emissions. For instance, the Ministry of Ecology and Environment (MEE) was established in 2018 to absorb more responsibility for environmental protection functions and has principal responsibility for managing GHGs and climate change policy.

The *14th Five-year plan* emphasizes the promotion of green development for 'harmony between humanity and nature' by promoting high-quality economic growth and high standard environmental protection. It restates the ambition to eliminate heavy air and water pollution in cities and aspires to expand forest coverage to above 24% of China's land area.

The central government recently released the *Opinion on Comprehensively Promoting the Construction of Beautiful China* (Xinhua, 2024) outlining further efforts for pollution prevention and control and ecological protection of land, water, and sea with goals formulated for 2027 and 2035.

Policy linked to air pollution control considered in the Outlook

In general, China has the ambition to replace high-emitting coal with lower-emitting natural gas to reduce local emissions. Key policies considered in our forecast include coal consumption caps, acceleration of coal-to-gas and coal-to-electricity switching, and retrofit projects (desulfurization for SO_2 control, denitrification for NOx control, and dust removal for PM control) in key industries. In transportation, China has pursued stricter emissions controls, promotion of new energy vehicles and car-sales restrictions (ICEs), and a massive expansion of public transit.

Air quality improvements have been registered with year-on-year decreases in China's national average pollution measures, such as PM2.5 levels. However, air pollution rebounded in 2023 (Qiu, 2023). This was partly due to unfavourable weather conditions, but mostly explained by increases in emissions from a change in thermal power production and industrial output in heavy industry that are both reliant on coal.

The central government will continue to reinforce increasingly stringent measures to improve air quality. To this end, the State Council issued the *Action Plan for Continuous Improvement of Air Quality* in November 2023, adding quantitative targets for a PM2.5 decrease during the *14th Five-year plan* to 2025 (State Council, 2023a). This Action Plan signals continuation and intensification of the air pollution control measures, such as:

- Controlling coal consumption, improving energy efficiency, and setting carbon emission peak targets; for example, all localities will be expected to incorporate coal-fired heating boiler replacement projects into urban heating planning
- Green upgrading of industries and clean energy substitution implemented in industrial furnaces to replace coal with electricity and gas
- Withdrawing backward production capacity in key industries (i.e. those with pollutants and GHG emissions significantly higher than the industry average) and accelerating development of clean, low-carbon, and efficient energy
- Accelerating the transition to a green transportation system with an emphasis on rail and new energy vehicles, and specifying coverage rates for EV charging stations

The list of actions on air pollution suggest a tight knit between government interventions on environmental protection, energy developments, and climate policies (elaborated next). However, lack of concern for environmental protection has been voiced in the past. For example, the Ministry of Ecology and Environment's *Environmental Audit Committee report* (2021) criticized the National Energy Administration for neglecting requirements for ecological and environmental protection, failing to integrate requirements in energy development, and preventing coal power capacity expansions in key polluted areas (MEE, 2021).

The recent rush by provinces to permit new coal capacity to bolster supplies also illustrates the challenging balance between environment, energy security, and decarbonization priorities. Of late, speeches by China's leaders lean in favour of stability and self-reliance (Government of China, 2022).

> China played a crucial role in facilitating the Global Biodiversity Framework concluded at COP15 as a step-change in biodiversity conservation.

Deepening climate policies

China's decarbonization success is paramount to achieving global climate goals. China is the world's largest carbon emitter accounting for about a third of global emissions and exceeds the total emissions of high-income regions North America, Europe, and the OECD Pacific as covered by DNV's global *Energy Transition Outlook* (DNV, 2023a).

Climate change was moved from China's State Meteorological Administration's remit in 1998 to the State Planning Commission (the predecessor to the National Development and Reform Commission (NDRC)), reflecting that climate change had become an issue of national interest and relevant for energy development. The motivation for decoupling economic growth from emissions has been predominantly domestic with the coal-dominated energy system seriously impacting China's soil, air, and water pollution.

Today, climate risks are also getting mounting domestic attention. Intensifying effects of climate change – with worsening weather extremes ranging from record-breaking heat and drought to the heaviest rains and floods (MEE, 2023) – are impacting water availability, energy supply, and food production alike and are threatening the stability of the country. Adaptation efforts have long been stepped up as part of national strategy since 2013 and most recently outlined in the *National Strategy for Adaptation to Climate Change 2035* (NCSC, 2022). The environmental protection and nature conservation agenda described previously is also interlinked with the climate agenda, such as enhancement of the carbon sink capacity of ecosystems. *However, given this report's emphasis on energy transition, the mitigation policy for* CO_2 *emissions will be in focus here.*

Emissions reduction is driven by the bold 'dual-carbon goal' – for CO_2 emissions to peak before 2030 and to achieve climate neutrality before 2060 – which is now a guidepost for policymaking and sets the tone for economic and social development in coming decades.

China communicates continued commitment to this goal, as mentioned in Section 2.1, despite no new bold announcements since the commitment was made, and despite the fact that macro-economic conditions and geopolitics over the past two years have augmented focus on energy shortages and seen a ramp up of coal plants.

Policy to further the agenda

China's **'1+N' policy framework** is designed to deliver China's dual-carbon goal with central government guidance provided in two documents. The '1' refers to the *Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy* (CCP and State Council, 2021), referred to as simply '*Guidance*' in the following pages. The 'N' refers to key sector policies, the first of which is the *Action Plan for Carbon Dioxide Peaking by 2030* (State Council, 2021a), in the following referred to as *'Action Plan'*, which details developments in energy and other key sectors building on the central government's *Guidance*. China's provinces are tasked to develop '1+N' strategies following the national framework and most have developed sectoral FYPs (2021-2025), but have yet to develop roadmaps for carbon neutrality (CCNT, 2023)

The central government has long emphasized the energy sector's contribution to a low-carbon and efficient energy system through a strengthened dual-control system. '**Dual energy control**' limiting total energy consumption and energy intensity has steadily been augmented since the *11th Five-year plan* (2006-2010) with binding targets. Recently (July 2023), the Opinion passed by the Central Commission for Comprehensively Deeping Reform (CCCDR) suggests a shift in future policy focus to '**dual carbon control**' that will limit the total amount of carbon emissions and carbon intensity (Lu, 2023), which is also clearly stated in the central government's recent *Opinion on Comprehensively Promoting the Construction of Beautiful China* (Xinhua, 2024).

Policies pursuing **electricity and gas market reforms** are also relevant for decarbonization. Reform in natural gas has been taken in steps (O'Sullivan, 2018) aiming for more market-oriented pricing that both stimulate domestic production (to curb imports) and encourage domestic demand aligned with the government's coal-to-gas switching policy (to curb pollution), while also seeking to control household prices (to avoid a consumer backlash). There have been several phases in China's electricity reform (Xu, 2022), deepening in 2015 with the central government's *Policy No. 9* (CCP and State Council, 2015). A key ambition is to improve the market-based pricing mechanism for electricity and other energy products (CCP and State Council, 2021) and it aims for a national unified power market system by 2025 and 2030 (NEA et al., 2022). Price signals are needed to enable a renewable dominated energy system – including flexible power production, storage capacity, ancillary services, inter-provincial electricity trading, etc. – as well as ensuring price responsiveness at the consumer level to provide operational flexibility and demand response. As of yet, the government's main goal is price stability and supply adequacy (while reform implies more volatility), and pricing structures in the power system continue to have a mix of market and administratively allocated generation volumes, electricity dispatch, and regulated power prices.

Policy linked to decarbonization considered in the Outlook

Common emission reduction measures, reflected in central government policy documents, involve improvement of energy and resource utilization driven by mandatory energy conservation targets and energy efficiency standards. The *14th Five-year plan* (2021-2025) focuses on controlling fossil-fuel consumption, enhancing energy efficiency, and increasing the non-fossil energy share in total energy consumption. Compulsory procurement and clean energy obligations on government entities combined with green electricity certificates and explicit emission costs from carbon pricing are central elements in China's regulatory portfolio.

To advance implementation, the *Opinions on Financial Support for Carbon Peaking and Carbon Neutrality* issued by China's Ministry of Finance (MOF, 2022a,b) outline a 'clear focus on supporting the construction of a clean, low-carbon, safe, and efficient energy system', and a 'green and low-carbon transformation of key industries and fields'. By 2030, it aims to have formed the tax and fiscal framework to be conducive to green and low-carbon development using a range of fiscal and taxation policies.

China has myriad plans and policy documents. Highlighted in the following are some key supply-side and demand-side initiatives that demonstrate the policy orientations in select energy areas and sectors. Initiatives are indicative of preferential government policy and support ranging from state-directed R&D to investment funding and fiscal incentives.

TABLE 2.3
A non-exhaustive list of supply-side policy initiatives

Supply-side	Policy focuses and key levers of change
Renewable Power[1]	**Insight: Renewables are front-and-centre in policies as the backbone of decarbonization** – 2005, the *Renewable Energy Law* makes renewables preferred development – 2006, the central government implements subsidy policy with national feed-in tariffs (solar, onshore wind); terminated in 2021 to pursue grid parity projects; renewables to compete for long-term contracts at or below tariffs paid to coal plants – *13th FYP* period (2016-2020) establishes generation targets over capacity to emphasize grid integration and directs provinces to reduce curtailment by 2020 – 2021, central government encourages local governments to have policy and support to development of renewable energy industries; support (auctions, funds, and electricity prices for new offshore wind and solar power) is decided at the provincial level, such as offshore wind with provincial subsidies projected until around the mid-2020s – *14th FYP* period (2021-2025) deepens market-oriented policies, such as renewable energy quotas and green power trade; electricity market reform efforts aim to optimize resource allocation for economic efficiency gains and decarbonization benefits – 2021, SASAC requires central SOEs to have at least 50% renewable generation capacity by 2025 – 2021, the *Action Plan* emphasizes active development of the 'new energy + energy storage' model – 2022, *14th FYP for Renewable Energy* directs flexible power sources to reach 24% of supply, energy storage for at least 30 GW by 2025, and pumped-storage at around 120 GW by 2030 – 2022, *14th FYP for Modern Energy System* aims for demand flexibility at 3-5% of max power load – 2023, the *Blue Book on the Development of New Power Systems (Blue Book)* formulates a 'three-step' development path to 2060 and is expected to be the basis for future policy development
Nuclear[2]	**Insight: Willingness to support for energy security reasons** – The nuclear power programme aims for safe and orderly expansions as nuclear meets energy needs, decarbonization, and energy security objectives – 2020 target (58 GW in operation and 30 GW under construction) was missed, suggesting higher priority on renewables expansion – 2021, the *Action Plan* outlines push for demonstration projects of advanced reactor types, e.g. small modular reactors and offshore floating reactors to promote nuclear energy development – 2022, *14th FYP for Modern Energy System* targets 70 GW installed nuclear capacity by 2025 – Internationally, China did not sign the COP28 declaration to triple nuclear energy capacity by 2050
Grids[3]	**Insight: Deepening investments for transmission, a unified market and high renewables share** – Infrastructure policy targets transmission expansion to facilitate transport, including cross-provincial transmission, and accommodate high renewable electricity penetration – 2021, power market policy aims for cross-provincial electricity trading – 2021, the *Action Plan* regarding trans-regional transmission states 'no less than 50% of electricity transmitted via newly constructed lines is generated from renewable resources' and structural reform will deepen for a unified national electricity market – 2021, the *14th FYP for National Economic and Social Development and Long-Range Objectives for 2035* emphasizes strengthening and deployment of high and ultra-high voltage transmission channels
Coal power[4]	**Insight: Enhanced efficiency and continuation to secure supply, cognizant of low utilization** – *13th FYP* targets efficient use of coal, mandating retrofits on existing coal-fired plants to reduce coal usage and emissions
Coal power[4] (continued)	– *14th FYP Coal Development Plan* emphasizes promotion and speedy construction of coal mines, giving play to the role of coal as a guarantee for energy security; seeks to restrict coal consumption, new coal power projects and strives to eliminate coal in key areas of air pollution by 2025; and aims to phase-out outdated capacity, accelerate energy saving upgrades and flexibility retrofits for coal to serve as flexible power and a system regulating source – 2023, capacity payments (guaranteed payments) based on installed capacity are introduced to ensure stability of supply while transitioning towards variable renewable power sources – 2023, the *Blue Book* outlines CCUS as part of the low-carbon transition of coal power (2030-2045)
Hydrogen[5]	**Insight: Near-term development for synergies between emission cuts, new energy + storage** – *14th FYP* has hydrogen as an area for future industry incubation and advancement to help store and transport renewable energy; R&D and innovation support aim to establish an industry value chain, such as the Daxing International Hydrogen Energy Demonstration Zone – SOEs are expanding investments; e.g. Sinopec aims to become China's largest hydrogen energy company with total investment over the next five years to exceed CNY 30bn yuan (more than USD 4bn) in e.g. hydrogen refuelling stations and renewable-based hydrogen production; PetroChina and CNOOC pursues investments in hydrogen supply and refuelling stations – 2022, the *Medium- and Long-Term Plan for the Development of Hydrogen Energy Industry* (2021-2035) targets annual renewables-based hydrogen production to reach 100,000 to 200,000 tonnes/yr to enable CO_2 emissions reduction of 1 million to 2 million tonnes per year; it aims for comprehensive hydrogen energy industry formation and significant increase in renewables-based hydrogen in final energy consumption by 2035 – The *Blue Book* envisions electricity and hydrogen energy provision to enable shifts in end-use consumption evolving between 2045 and 2060
CCS, DAC[6]	**Insight: Recognized decarbonization role but last choice and later advancement** – Long-standing government funding to research and pilot projects (around 100 CCUS demonstration projects with various scales, as of November 2022) in different sectors, including in power, cement, and chemical industries – China's *NDC and Long-Term Low Greenhouse Gas Emission Development Strategy* state policy and support to push forward demonstration and industrial application of large-scale carbon capture, utilization, and storage – CCUS scaling is expected to rely on carbon pricing and mandates, such as requirements on SOEs, to realize carbon neutrality by 2060. Furthermore, low-cost loans are available through the Carbon Emission Reduction Facility of the People's Bank of China – Direct air capture (DAC) is recognized as an advanced CCUS technology for the longer term, but not widely discussed yet, and barely sees relevant policy support

Policy insight summary:

- Renewable power, flexibility sources, and non-fossil supply are key pillars in the transition with supremacy and steadfast advancement by government policy and support. Coal is assigned a complementing role in power
- Policy to transition supply sectors favour advancement of renewable electricity, green hydrogen and hydrogen derivatives
- CCUS to decarbonize fossil sources is acknowledged but policy and support for its advancement, in terms of commercialization and large-scale application, appear to be at the tail end of the transition

1. NDRC (2023b); NEA (2023a,b); SASAC (2021); State Council (2021b); NDRC et al. (2022a,b); Hove (2022)
2. CCP and State Council (2021); State Council (2021a); NDRC et al. (2022)
3. CCP and State Council (2021); Government of China (2021); State Council (2021a, 2023b); Hove (2022)
4. State Council (2021a); OIES (2022); NDRC (2023a)
5. Government of China (2021); State Council (2021a); NDRC (2022); NEA (2023b)
6. GCCSI (2023b); UNFCCC (2021a)

TABLE 2.4

A non-exhaustive list of demand-side policy initiatives

Demand-side	Policy focuses and key levers of change
	Insight: Longstanding policy for electrification and industrial advantages in the road segment; aviation and shipping segments move at slower pace
Transportation[1]	**Road:** – 2009, official *New Energy Vehicle Programme* (NEV = battery electric, plug-in hybrid electric, fuel cell electric vehicles) with *Ten Cities, Thousand Vehicles Programme* for NEV development through large-scale pilots – Vehicle purchase subsidies from central government extended through 2022 for passenger vehicles; tax incentives 2014-2023 with purchase tax and annual vehicle tax exemptions – Controls through tightened fuel efficiency regulation and restrictions on ICE sales; e.g. limits on annual number of license plates for conventional fuel vehicles – 2017, NEV mandated quotas for sales on vehicle manufacturers that a certain percentage of vehicles sold are battery-powered; NEVs to account for about 20% of new vehicle production by 2025 – 2020, *Energy-saving and New Energy Vehicle Technology Roadmap (2.0)* commissioned by the Ministry of Industry and Information Technology (MIIT) outlines NEV production and sales volume targets of over 20% by 2025, 40% by 2030, and 50% by 2035, and envisions BEVs to have above 90% share of targets – 2020, the State Council's *NEV Industry Development Plan (2021-2035)* directs national, provincial, and municipal requirements and funding; 2025 targets include: EV power consumption efficiency (12 kWh / 100 km), NEVs to reach 20% of new sales (all vehicle types), acceleration of infrastructure rollout (charging/swapping infrastructure, hydrogen refuelling), battery traceability and end of life responsibility on producers – 2020, *Notice on Carrying out the Demonstration and Application of Fuel Cell Electric Vehicles* sets new policy replacing direct purchase subsidy mechanisms to consumers with incentive funds and awards providing support (CAPEX and OPEX) to urban clusters for industrialization of key core technologies of FCEVs, demonstration applications, and hydrogen ecosystems – 2022, *Medium- and Long-term Plan for the Development of Hydrogen Energy Industry (2021-2035)* aims for 50,000 FCEVs on the road by 2025 – *14th FYP for Green Transportation* targets pilot applications of hydrogen vehicles and acceleration of NEVs in public transportation, aiming to increase the share to 72% of all ground bus vehicles (at about 66% in 2020) by 2025 **Maritime:** – 2015, domestic emission control areas with gradual implementation of requirements covering SOx and NOx air pollutants from ships – A draft amendment to the *Marine Environment Protection Law* provides financial support and implements preferential policies to enable the upgrading and operation of shore power supply facilities, as well as the building of vessels powered by clean and new energies – 2021, the *Action Plan* states faster upgrading of old ships and development of ships fuelled by electric power and liquefied natural gas (LNG) with government support – *14th FYP for Green Transportation* sets ambitions to lower shipping emissions, including promotion of shore power and 'road-to-water' shifts in transportation of cargo, expanding emission control areas, stricter emission control requirements, and promotion of LNG – International collaboration, such as the Shanghai port-Los Angeles port Green Shipping Corridor aims to demonstrate the feasibility of zero carbon container ships by 2030 **Aviation:** – The *Action Plan* push for the substitution of advanced liquid biofuels and SAF for traditional fuels and improvement of fuel end-use efficiency – The *14th FYP for Green Civil Aviation Development* (January 2022) sets expectation for the aviation sector to achieve breakthroughs in promoting the commercial use of SAF, aiming to raise SAF consumption to over 20,000 tonnes in 2025 and cumulatively to 50,000 tonnes by 2025 and to establish an expected goal for reducing fuel use per tonne-km for air transport fleet to 0.293 kg and reducing carbon emissions per tonne-km by 4.5% (to 0.886 kg) from 2020 levels – *The 14th FYP for Bioeconomy Development* encourages areas with good conditions to promote and pilot biodiesel use and advance the demonstrative use of aviation biofuels – *The 14th FYP for Renewable Energy Development* (June 2022) aims to scale up efforts in non-food liquid biofuels, R&D, and promotion of advanced technology and equipment for biodiesel and aviation biofuel production – Domestic aviation is expected to be included in the national ETS scheme in the future
	Insight: Upgrade and industry prioritization to modernize economic structure
Manufacturing[2]	– Longstanding policy for demonstration and establishment of eco-industrial, circular economy, and low-carbon industrial parks – 12th FYP period (2011-2015) emphasizes industrial transformation and upgrade, focusing on seven 'strategic emerging industries', including new energy, energy conservation, environmental protection, and clean-energy vehicles; the central government mandates support to favoured industries – 2015, the *Made in China 2025* innovation plan aims to push the industrial structure to the middle and high end, targeting higher value-added manufacturing and increased production in high-tech products and services – 2021, the *Guidance and Action Plan* outline they will control coal consumption in energy intensive industries, curb energy-intensive and high-emission projects, shut down outdated production capacity, and promote coal substitution (e.g. coal-to-gas and coal-to-electricity) – 2021, China's *NDC* states ambition to increase the proportion of clean and low-carbon energy use and encourage factories and industrial parks to develop and utilize renewable energy – 2021, *Development Plan for the Circular Economy* outlines initiatives during the *14th FYP* period – such as recycling, remanufacturing, and green product design – and aims to improve resource utilization for a 20% increase in resource productivity and 13.5% reduction of energy consumption (see Table 2.2), and set tonnes targets for use of scrap steel and production of recycled non-ferrous metals – 2021, the *14th FYP* elevates the status of manufacturing to move China up the value chain by gearing up its clean modernization and upgrading its industrial system; R&D spending is to increase by more than 7%/yr – 2022, *14th FYP for Modern Energy System* outlines promotion of the expansion of electric boilers, electric kilns, electric power, and other applications in industrial production – 2023, the *Blue Book* envisions in-depth promotion of electrification in the industrial field prioritized for development (2030-2045) and hydrogen (2045-2060) to become main bodies meeting energy end-use – 2023, the *Catalogue for Guiding Industry Restructuring* is updated, as flagged in China's NDC submission (2021), to guide investor alignment with national policy priorities; this signals a strategic shift to high-tech industries and environmental priorities
	Insight: Efficiency and coal substitution policy to safeguard quality of life
Buildings[3]	– Policies favour coal-to-gas and coal-to-electricity switching – The *Implementation Plan for Carbon Emissions Peaking in Urban-Rural Construction* sets a 65% building electrification rate by 2030, pushing for full electrification of new buildings – Available subsidies to household heat-pump investments to increase the electricity share of buildings' energy demand and instalment of rooftop solar PV (e.g. for 50% of new public buildings and new factories) – *14th FYP* sets targets relating to energy conservation of new buildings and renovation of existing building stock – All localities are required to incorporate coal-fired heating boiler substitution projects into urban heating planning and promote clean, low-carbon heating using heat pumps, biomass, geothermal energy, and solar energy according to local conditions

Policy insight summary:

- End-use sector policies will focus primarily on improving energy consumption patterns and switching end-use demand from combustion of fossil fuels to increased renewable energy use and hydrogen
- Efficiency and electrification will continue to be key pillars and enjoy favourable government policy
- Hard-to-electrify transport segments, aviation and shipping, have less concerted decarbonization policy

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1. NDRC (2022); MOT (2017, 2020, 2021); State Council (2020); State Council (2021a); Yiru et al. (2022)
2. NDRC (2021, 2023b); NEA (2023b); CET (2023)
3. State Council (2023); OIES (2022); State Council (2021a); Yu et.al (2022)

How our forecast accounts for China's carbon pricing

China's national carbon emission trading system (ETS) is indicative of a gradual transition to a hybrid approach to decarbonization consisting of both market mechanisms and direct regulation. It will contribute to achieving China's dual-carbon goals and is mentioned as part of the '1+N' policy framework.

The ETS targets energy-intensive and high emitting sectors, such as power, refining, chemicals, steel, building materials, non-ferrous metals, paper, and aviation. Presently, the national ETS covers power with around 2200 entities, 4.5 billion tonnes of emissions, and approximately 40% of the country's emissions. Emission permits have free allocation based on an output-based benchmarking method (see ICAP, 2022).

The *14th Five-year plan (2021-2025)* signalled expansion of the national ETS to eventually cover high-emission sectors (70% of emissions). The EU's carbon border adjustment mechanism (CBAM) adds urgency to the extension of scope to other industry sectors. Exporters of carbon intensive CBAM covered goods (aluminium, cement, electricity, fertilizers, hydrogen, iron, and steel) to the EU need to report embedded emissions during the transitional period between 2023 and 2026, with payments through surrender of CBAM certificates starting in 2026.

China's national ETS will take time to mature and its design will be fine-tuned. Its expansion will likely mirror the EU CBAM exposure; industry over-capacity and potential for decarbonization will also influence the sequence of inclusion. Steel, building materials, and aluminium are likely top candidates to be the first new sectors.

Existing regional ETS pilots will continue to operate in parallel with the national market in the near term to 2035. Other carbon markets – such as the Certified Emission Reduction (CCER) scheme, China's domestic voluntary carbon market – are set for relaunch and will also work in tandem with the national ETS. Emitters in the national ETS that exceed their allowances may acquire CCER credits to offset emissions; while the allowed use of CCER credits is limited to up to 5% of verified emissions, several credit options for compliance and several parallel carbon market schemes are likely to limit increases in the national ETS price level.

To date, improving the efficiency of coal plants has been the primary emissions abatement measure in response to tightened benchmarks. Future ETS adjustment is expected with a switch to an absolute cap on emissions and auctioning by the early to mid-2030s. However, this shift is not likely to happen until knowing emission levels after emissions have peaked. As power progressively decarbonizes, price-setting will increasingly be the industry abatement measure to trigger the necessary decarbonization technologies and options, such as CCUS and hydrogen, suggesting a surge in the carbon price trajectory after 2040 to achieve carbon neutrality by 2060. The upward pricing trend is underpinned by the inclusion of more sectors and expanding coverage in China's national emissions trading scheme.

TABLE 2.5
Our projection for China's regional average carbon price level and trajectory

2025	2030	2040	2050
USD 10/tCO_2	USD 20/tCO_2	USD 40/tCO_2	USD 90/tCO_2

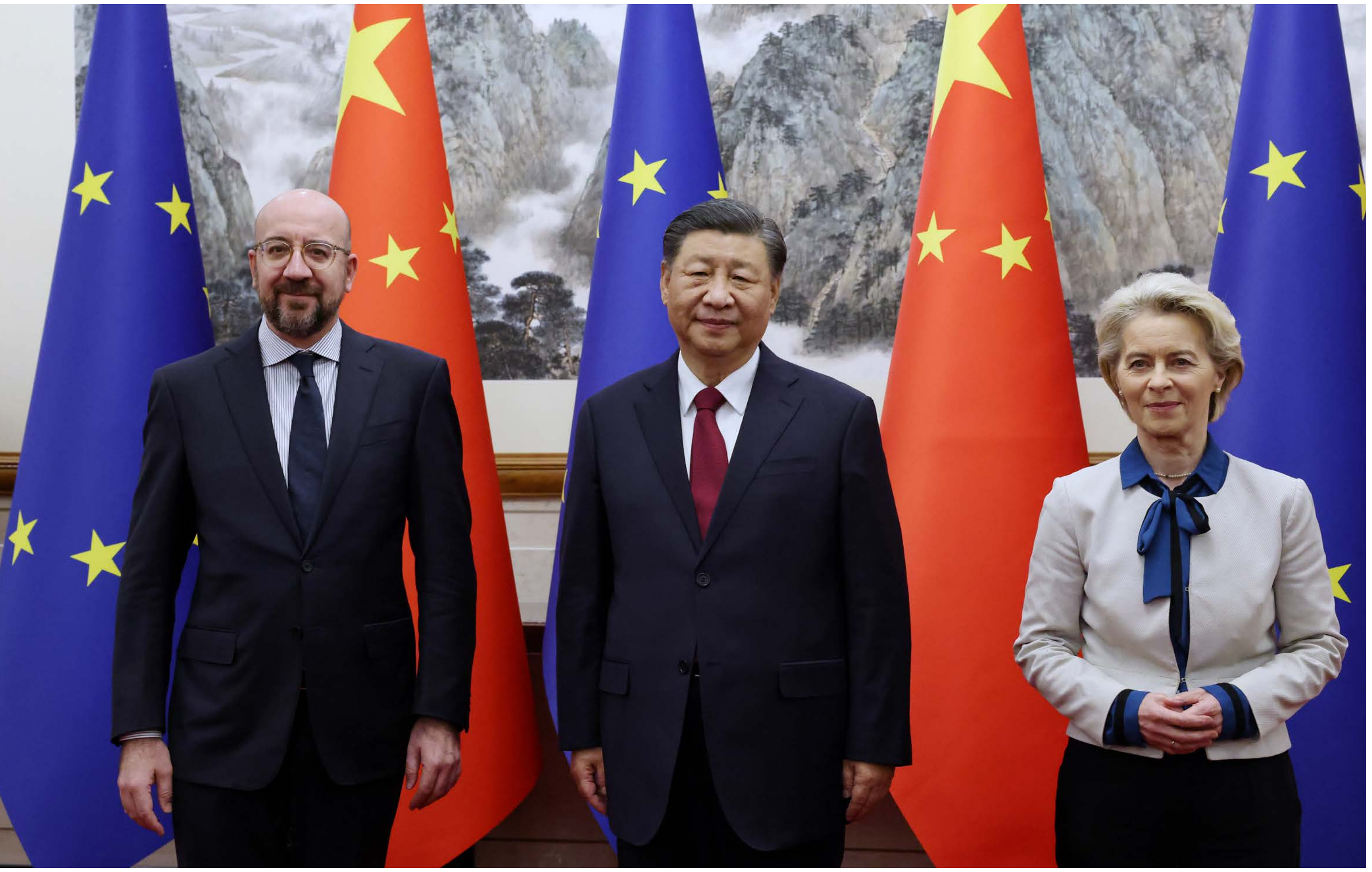
For comparison, DNV projects the regional average carbon price level at USD 56/tCO_2 (2050) in the North America region, and USD 250/tCO_2 (2050) in the Europe region. For a more detailed discussion of the carbon price trajectories in the 10 world region's covered in DNV's global *Energy Transition Outlook*, please refer to the 2023 publication (DNV, 2023a).

Note: DNV has (DNV, 2023b) assessed the necessary pathway to achieve global net zero by 2050 elsewhere.

Our pathway requires China to frontload ambitions and reach net zero in the late 2040s. To this end, the required average carbon price level is USD 100/tCO_2 in 2030 and USD 200/tCO_2 in 2050. This is challenging, given the most likely forecast of China's transition to 2050 projects emissions reduction of around 8 GtCO_2 and a net zero future requires an additional reduction of around 5 GtCO_2 by 2050. Nonetheless, adopting such an ambition of frontloading emission reductions would coincide with the centenary celebration of the People's Republic of China in 2049.

2.3 China and the global transition

China is taking an active role in climate diplomacy and expanding its climate-change cooperation (MEE, 2022). With growing economic power, China has become more assertive on the global stage since 2010.



EU-China Summit. December 7. 2023 ©European Union

President Xi Jinping supports a reshaping of the international system and economic ties have been enhanced worldwide in which energy and infrastructure projects are centrally placed, especially within middle- and low-income countries and regions. China’s key motivations are to reduce dependence on the European and US markets by expanding trade with others, as well as to raise China as an economic hub in a flourishing global economy. While this Outlook focuses on China’s domestic energy transition, we highlight three key policy-related areas that shape the global energy transition.

A greening Belt and Road Initiative
China’s *Belt and Road Initiative* (BRI), officially announced in 2013 to build a new ‘Silk Road Economic Belt’, is at the heart of China’s foreign policy strategy and is funding infrastructure projects and special economic zones. BRI stretches globally and 150 countries had signed agreements for cooperation as of April 2023; BRI investments extend into Asia, Africa, the Middle East, and Latin America.

Critically for the energy transition and climate objectives, China made a ‘no new coal overseas’ announcement to the UN General Assembly in September 2021, pledging to support green energy developments instead of coal-fired power plants and to overall decarbonize overseas projects. The 2021 *Action Plan* states ‘we will make overseas projects more environmentally sustainable, develop a BRI energy partnership characterized by green development and inclusiveness, and expand the export of new energy technology and products’. The first half of 2023 had 55% of the BRI’s energy spend going into renewables (GFDC, 2023), and after a period of overall BRI investment pause in overseas energy projects (Baxter, 2023) and scale back, there are indications of a reboot of the initiative with emphasis on smaller and greener projects. President Xi Jinping is promising an extra USD 100bn in development funding (CHN, 2023).

Supporting the global low-carbon development agenda is a way for China to show that it is honouring its green pledges. It is mutually beneficial for the host country and China domestically. The latter because it helps boost demand from new emerging market destinations which helps diversify revenue away from mature (Western) markets in a context of fragmented trade with tariff and non-tariff barriers. It also buffers excess capacity in China's renewable energy manufacturing industries and paves the way for long-term exchanges as energy infrastructures are built following Chinese standards. Middle- and low-income countries, on the other hand, see BRI as enabling trade and investments.

The G7 infrastructure initiative – the *Partnership for Global Infrastructure and Investment* (PGII) – launched at the Elmau Summit (2022), similarly focuses on infrastructure needs in developing economies. Through public and private investments in pressing priorities – such as climate change, energy crisis, and sustainable infrastructure – the G7 aims to mobilize up to USD 600bn by 2027, while also leveraging synergies with Just Energy Transition Partnerships (JETPs).

While both BRI and the PGII are illustrative of geostrategic positioning, such overseas investment (to middle- and low-income regions) is helping access to finance much needed energy investments.

Cleantech competition is triggering an industrial policy race
China is a front-runner region in the energy transition and Chinese firms have played an extensive role in both driving down the cost of cleantech and making adoption of technologies affordable to the world at large. China has extensive leadership in cleantech areas and the materials and metals to support them thanks to government policy, a large home market supporting economies of scale, complete renewable energy industrial chains, and capabilities in manufacturing, installation, operation, and maintenance. The frontrunner position is evidenced by China accounting for more than 80% of global solar cell exports, more than 50% of lithium-ion batteries, more than 20% of EVs (Xiaoying, 2023), and Chinese manufacturers supplying nearly 60% of installed wind capacity worldwide in 2022 (Okamoto, 2023).

Lately, the energy transition is increasingly entangled in geopolitical rifts and there is a race to roll out industrial and sectoral policies among industrialized high-income regions (North America, Europe, OECD Pacific) to de-risk and support strategic positioning in clean energy value chains. China will respond – as we have seen in tightened export controls on e.g. gallium, germanium, and graphite – aiming to defend its technological leadership and value chain advantages. Chinese companies will continue to internationalize with production outside China, seeking to mitigate restrictive trade policies by moving operations overseas. Already, Chinese solar panels going to the US and EU markets have production

China hosted the third Belt and Road Forum for International Cooperation, October 2023 ©Xinhua/Chen Bin

President Joe Biden and President Xi Jinping, November 2023 in California ©Doug Mills / The New York Times via AP, Pool / NTB

locations in Southeast Asia's ASEAN countries. However, scrutiny over inbound investment across different jurisdictions may restrain actual investments.

Defining and establishing a level playing field for economic cooperation is in flux at the time of this report. Climate and cleantech multilateral initiatives are taking new shapes and new region alliances and partnerships are evolving in fields such as in green hydrogen, mining and processing, and trade in commodities. China will continue to play a central role given its natural resource base and existing position in materials and transition-related technology value chains.

The global competition in cleantech is clearly beneficial considering that technology deployment in middle- and low-income countries and the speed of the energy transition will predominantly be determined by the cost of transitioning. In DNV's energy forecasting, we take energy security considerations and efforts to de-risk and reshore manufacturing value chains into account. We do not foresee a decoupling of global supply chains and expect future technology cost-learning dynamics to continue enjoying global benefits. For a more detailed discussion, please refer to DNV's *Energy Transition Outlook* (DNV, 2023a).

Climate momentum in US and China relations

Internationally, after years of strained cooperation, there has been extraordinary commitment on both sides (from climate envoys Xie Zhenhua and John Kerry) to keep dialogue open. The *Sunnyland Statement* (US Department of State, 2023) issued following the meeting between President Joe Biden and President Xi Jinping ahead of COP28 rejuvenated the US-China dialogue on the energy transition and climate action and set the tone for further engagement in 2024.

The Statement included ambitions for cooperation in key areas, such as controlling methane emissions, boosting renewable energy deployment (both countries supporting the G20 Leaders Declaration on tripling global renewable energy capacity by 2030), advancing CCUS with each country promising 5 large-scale CCUS projects (industrial and energy) by 2030, and deepening policy exchanges on energy-saving and carbon-reducing solutions in end-use sectors. Operationalizing the working group, agreed back in 2021, to enhance climate action in the 2020s (US Department of State, 2021) was given new momentum to advance climate action in the next decade on issues such as methane, deforestation, and the circular economy.

While long-term stability in relations remains to be seen, such working groups can sustain progress despite electoral shifts. Furthermore, the Statement endorses sub-national cooperation like the kind that already exists between China and California on emissions policy, which will likely continue regardless of the 2024 US presidential election outcome.

Overall, the Statement signals efforts to balance cooperation and competition in China and US relations, and commitment among the world's two largest emitters is a positive for the energy transition.

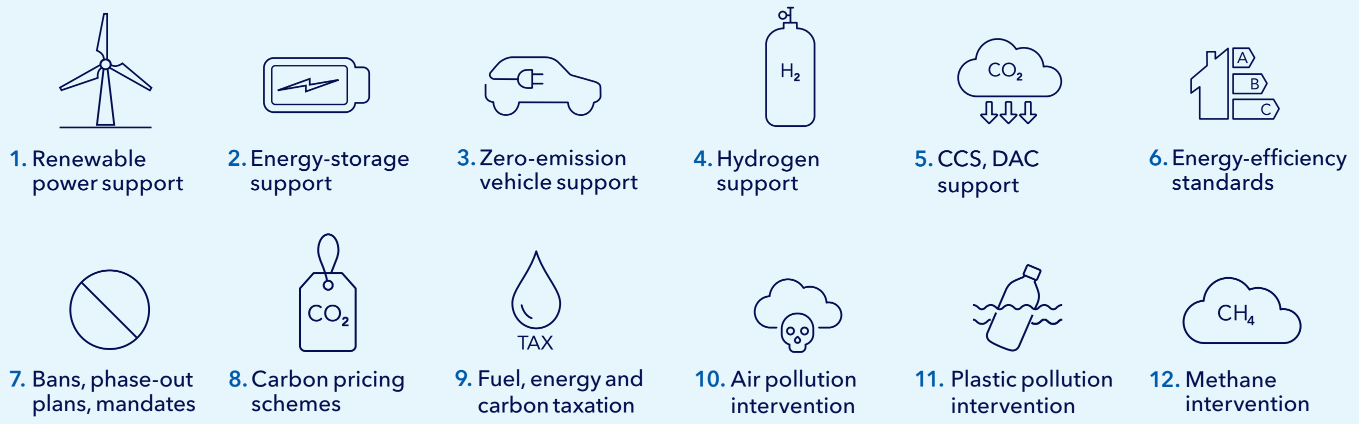
2.4 Implementing policy in the outlook

Our model is informed by the policies set out in China. Policy factors, as seen in Figure 2.1, span the supply and demand sectors. We have also factored in our own assessments of the state of play in the various sectors of the economy based on our global energy sector knowledge, our technical and commercial expertise, and discussions with a broad range of stakeholders. On announced policy goals and pledges, such as those submitted to the Paris Agreement, we do not assume that these will be met and hence do not pre-set our Energy Transition Outlook model to achieve them.

From DNV's global *Energy Transition Outlook* (DNV, 2023a), we have a comprehensive discussion of the policy factors influencing the forecast and we advise the reader to visit that source for a detailed description of how we account for policy in our forecast. The same policy factors are incorporated in the China forecast. For assumptions on China's carbon-price trajectory, please refer to the earlier highlight and Table 2.5.

FIGURE 2.1

Policy factors included in our Outlook



3 ENERGY DEMAND

Energy demand in China grew rapidly from 2002 to 2014, but is now slowing owing to several structural reasons. Energy demand is expected to plateau in 2029 at around 122 EJ for five years before gradually declining towards 104 EJ by mid-century.

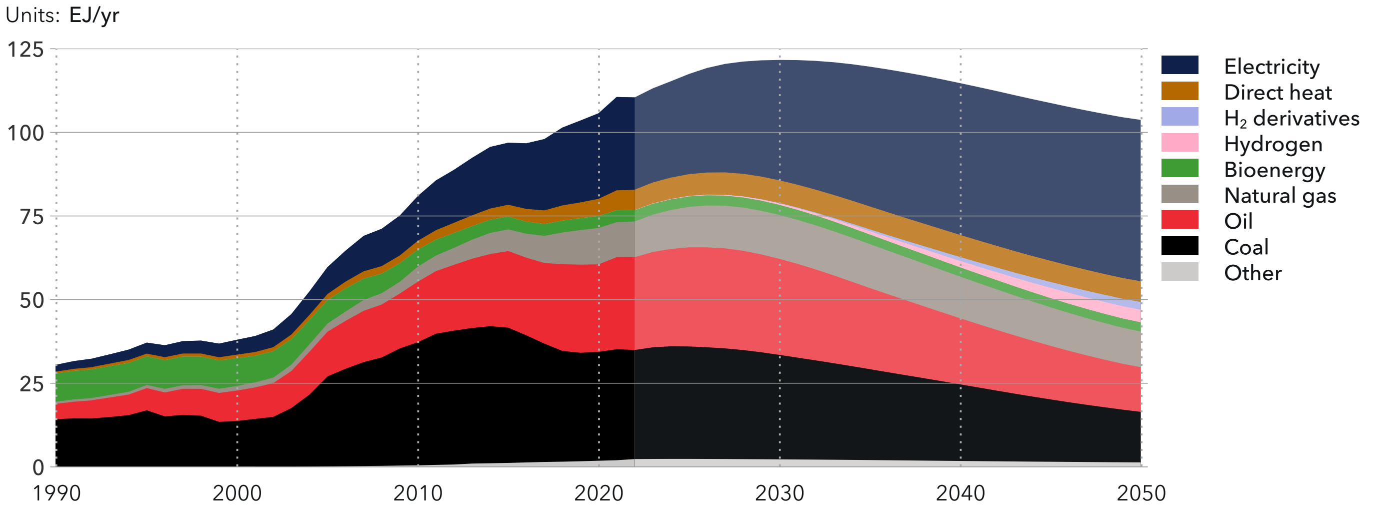
China's total energy demand has been growing at an average of 3% per year for the past five years. In 2022, energy demand growth slowed to approximately 1%, reflecting sluggish economic growth and weakened consumer confidence and spending during that period. However, as economic activity rebounded in 2023, albeit not reaching pre-pandemic levels, energy demand surged by 5.7%, according to preliminary official figures. This growth, predominantly fuelled by fossil fuels, has set new global records for China's fossil CO_2 emissions in 2023. In the remaining years of this decade, we expect China's energy demand to decelerate for a variety of reasons, including: the demographic shift now underway, a decreased dependence on heavy industry as a catalyst for growth, an increase in energy efficiency, and slower overall economic growth. These trends will in fact lead to a plateauing of energy demand at 122 EJ from 2029 for a decade or so, before a steady decline in energy demand to 104 EJ by 2050.

As Figure 3.1 shows, fossil fuels directly met 65% of final energy demand in 2022, but fossil fuel's share was in fact significantly higher than that, given that 60% of 2022's grid-connected electricity was from coal and 6% was from gas. By 2050, excluding the remaining 7% fossil fuel share in the power mix, the fossil share in final energy demand will be 38%. The share of electricity is projected to increase to 46.5% by 2050 from 25% in 2022, while hydrogen is anticipated to rise from almost 0% in 2022 to 3.6% of final energy demand in 2050.

Figure 3.2 shows the final energy demand by sector. By 2050, manufacturing will still be the largest sector of energy demand with a 42% share of the total, down from 51% today, while buildings' share will grow from 19% to 28%. Transport's share will initially grow from 16% now to 18% by 2027, then decline to 14% in 2050 as electrification – and hence efficiency – of road transport scales from the late 2020s.

FIGURE 3.1

Final energy demand by carrier



Historical data source: IEA WEB (2023)

In China, the demographic shift, mainly the declining and ageing population and rural-urban migration, affects all energy demand sectors and further reduces available labour (with the working age population already having peaked around 2010), creating labour cost and productivity challenges. Additionally, shifts in consumer preferences and demands, influenced by changing demographics, can alter the types of goods produced and affect energy usage within the manufacturing sector.

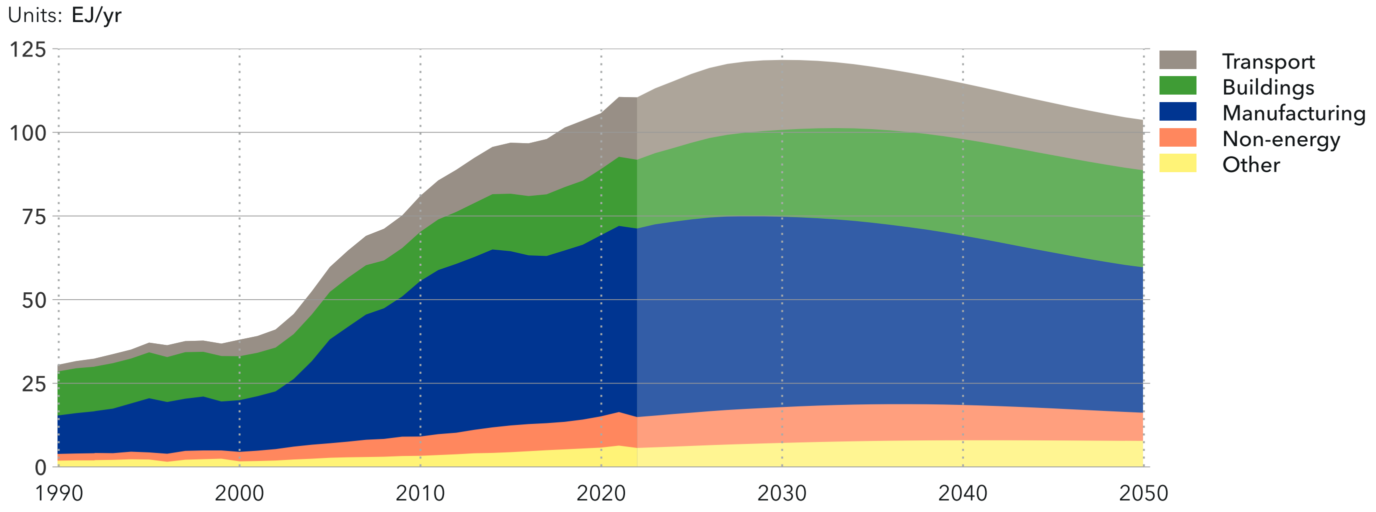
The declining population is nevertheless becoming more prosperous, and so the density of passenger vehicles is expected to undergo significant growth, with a potential peak around 2038, reaching over 70% more than the 2022 count of about 252 million vehicles. However, a high level of urbanization and extensive build-out of public transport will mean vehicle density remains lower than in OECD countries. In the 2040s, a reduction in population alongside greater automation and car sharing will reduce vehicle numbers. Aviation is likely to double through to 2050 as an increasing number of China's residents become middle class, including many pensioners who would like to travel.

The urbanization rate in China is growing rapidly; today, almost two-thirds of the China's population lives in cities, mostly in new high-rise buildings. Small family sizes and an increased standard of living will see building stock in China grow by 28% for residential buildings and 157% for commercial buildings by 2050. However, a strong focus on energy efficiency will limit growth in buildings' energy use, which is relatively stable from 2030 onwards. While energy needs for heating, water heating, and cooking will be relatively stable, energy for cooling increases more than six-fold over the next 20 years, and by 2050 it represents 29% of China's buildings' energy use, just behind energy needs for heating with 30% share.

> The carbon intensity of China's energy demand reduces from today's 104 gCO_2/MJ to 34 gCO_2/MJ over the coming three decades and is first and foremost coupled with the reduction in China's coal consumption.

FIGURE 3.2

Final energy demand by sector



Historical data source: IEA WEB (2023)

3.1 Transport

Demand for energy services in China is poised for significant growth, but the resulting energy demand will move in the opposite direction: decreasing slightly from 19 EJ in 2022 to 15 EJ by the year 2050, after peaking at around 21 EJ at the end of this decade. More transportation with lower energy demand will be delivered by the efficiencies inherent in electrification as well as the growing use of low-carbon fuels.

The global transportation sector is poised for significant growth and a profound transformation, and so is the Chinese transportation sector. Anticipated developments from 2022 to 2050 include a 18% larger vehicle fleet, a tripling in passenger flights, and a close to two-fold rise in rail passenger and rail freight numbers. In 2022, these diverse transport activities collectively consumed 19 EJ of energy. Despite the heightened activity expected in 2050 with increased transportation of goods and people, energy consumption in the sector is projected to be just 15 EJ by mid-century. This reduction primarily stems from substantial efficiency gains achieved through the widespread electrification of road transport.

Ultimately, the mitigation of carbon emissions in the transportation sector hinges on addressing the fuel challenge. Emissions stemming from transportation are dispersed across road vehicles, airplanes, and ships, posing significant challenges in terms of effective capture. Beyond CO_2 these emissions frequently encompass potent GHG and detrimental particulate matter, which can exert adverse effects on both environmental conditions and human health. Electrification of road transport and the adoption of biofuels and hydrogen (and its derivatives) in maritime and aviation will result in an almost halving of China’s transport sector emissions by 2050.

Road

Over the past two decades, China has played a pivotal role as the primary catalyst for the global growth of refined oil products such as gasoline and diesel. However, in mid-2023, Chinese oil giant Sinopec made an unexpected announcement that went largely unnoticed: the company now anticipates a peak in gasoline demand in China in 2023, marking a shift of two years earlier than its previous projections. The primary factor behind this change is the rapid increase in the number of EVs on the roads. We forecast that by 2050, oil demand in China's road sector reduces by 94%, with large implications for domestic oil production and oil imports as well.

China's consumers are rapidly embracing EVs, which accounted for around 20% of new passenger vehicle sales for the entire year 2022 and around a quarter in recent months, meaning the country has already exceeded its target of 20% New Energy Vehicle (NEV) sales share by 2025 (see Table 2.4). The Chinese government has consistently committed to the development and widespread adoption of EVs, motivated by concerns about the adverse health effects of local air pollution and the nation's dependence on imported oil, along with the associated energy security challenges.

In December 2022, China ended its national NEV subsidy scheme. However, in June 2023, the country introduced a significant tax package totalling CNY 520bn over four years. NEVs purchased in 2024 and 2025 will be entirely exempt from purchase tax, up to CNY 30,000 per vehicle, but this maximum benefit will be halved for purchases in 2026 and 2027. The government’s move aims to propel the EV market and aligns with China’s broader goals, including achieving a 50% NEV sales share by 2030 in key air pollution control regions and a 40% sales share nationwide by the same year. The tax breaks mark a significant effort to revive the automotive industry amidst sluggish sales and the phase-out of previous subsidies.

Close to 5% of the passenger-vehicle fleet is now either battery-electric or plug-in hybrid vehicles. Additionally, the internal combustion vehicle fleet is becoming more efficient, thanks to increasing fuel-economy targets. We forecast the uptake of EVs in China to be the fastest among all regions, with EVs reaching half of new passenger vehicle sales there by 2027 and EVs constituting half the entire passenger fleet of vehicles by 2035. Another aspect of EV uptake is that these vehicles are much more prevalent among ride-hailing vehicles in China, constituting nearly 40% of the fleet, in contrast to privately owned vehicles.

Two- and three-wheeled vehicles, a sub-sector of road, are already a step further than passenger vehicles in the transition to zero-emission propulsion. For over a decade, fuel demand for two- and three-wheeled vehicles has been in steep decline, with around 40% of sales in this category being electric today. By the end of this decade, electric two- and three-wheelers will make up 97% of the fleet.

> We forecast that by 2050, oil demand in China's road sector reduces by 94%, with large implications for domestic oil production and oil imports as well.

FIGURE 3.3

Transport energy demand by carrier

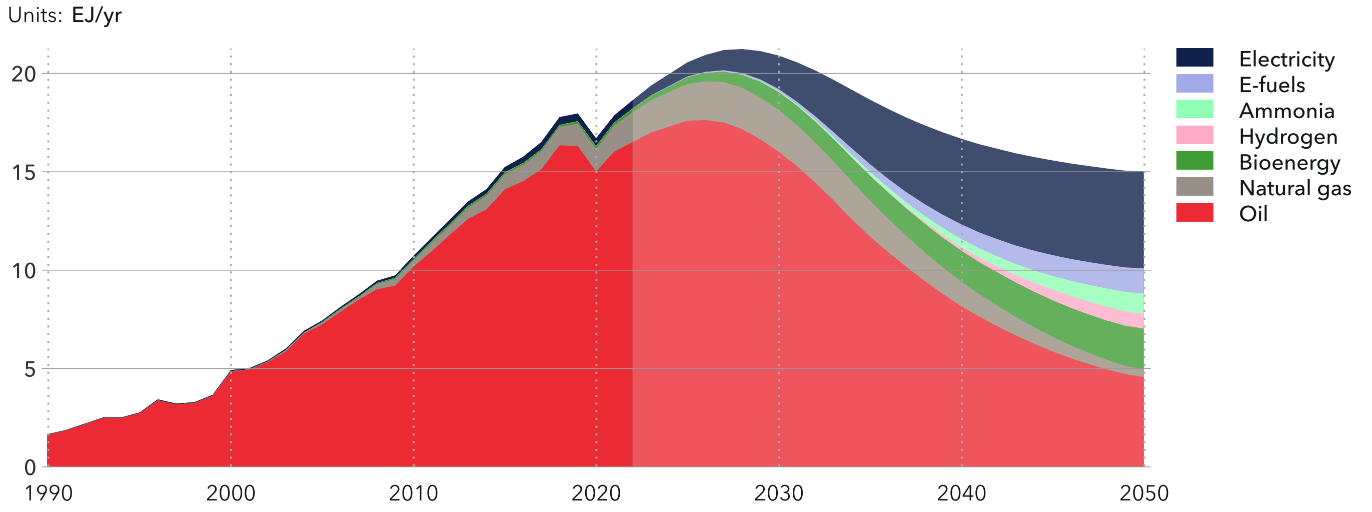
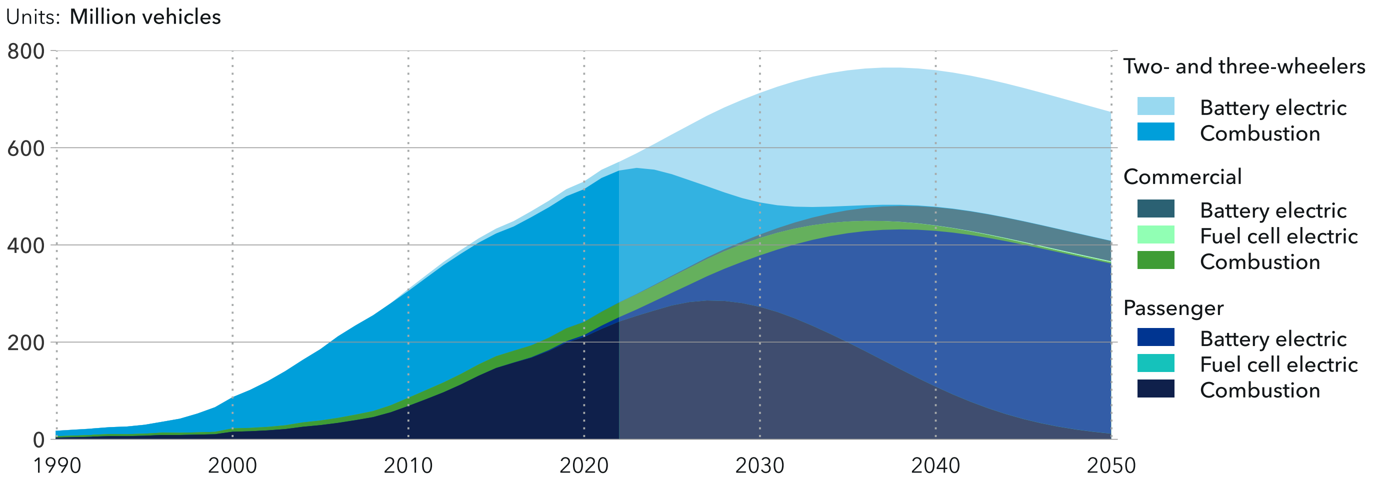


FIGURE 3.4

Number of road vehicles by type and drivetrain



Combustion vehicles include ICEs and PHEVs.
Historical data source: Marklines (2022), IEA EV Outlook (2023), EV Volumes (2022)

While the gasoline peak is expected by 2023, diesel demand for heavier vehicles is expected to continue growing for a short period. However a significant transformation is also taking place in this segment: electric, fuel cell, and battery-swapping alternatives have rapidly entered commercial vehicle sales. We forecast that the share of commercial vehicles adopting zero-emission alternatives will surpass 50% by 2030 and grow to around 90% within the coming decade.

While the sale of EVs is growing continuously and exponentially in all road sub-sectors, fuel-cell vehicles in the passenger segment play close to no role. However, fuel-cells are seen as an alternative in the commercial segment by China's government. By the end of 2023, fuel-cell vehicles on China's roads were in the low ten-thousands only and will increase only marginally to 50,000 by 2035. The goal of China's government to have one million hydrogen-powered vehicles by then will be met slightly later in the early 2040s. We see a supply shortage of low-carbon hydrogen and high costs as the main barriers to increased uptake.

Maritime

The maritime sector holds a crucial position on the economy of China, given the extensive coastline of around 14,500 km and immense dependence on international trade. Transporting cargo on keel stands out as the most efficient mode in terms of emissions per ton-mile. However, it is important to note that ships are characterized by significant capital investment, with an expected lifetime exceeding 20 years, which results in a relatively inert sector when it comes to transformation.

China recently surpassed Greece as the global leader in maritime fleet ownership by gross tonnage (GT). For the first time, the Chinese-owned fleet now stands at 249.2 million GT, securing the top spot (Longley, 2023). Greece follows closely in second place with 249 million GT. Despite Greece holding the first position for the past decade, China's role as the world's manufacturing hub, its resilient cargo trade, and robust financial support for the shipping sector have propelled it to the forefront of the industry, particularly in the dry bulk and container ship sectors.

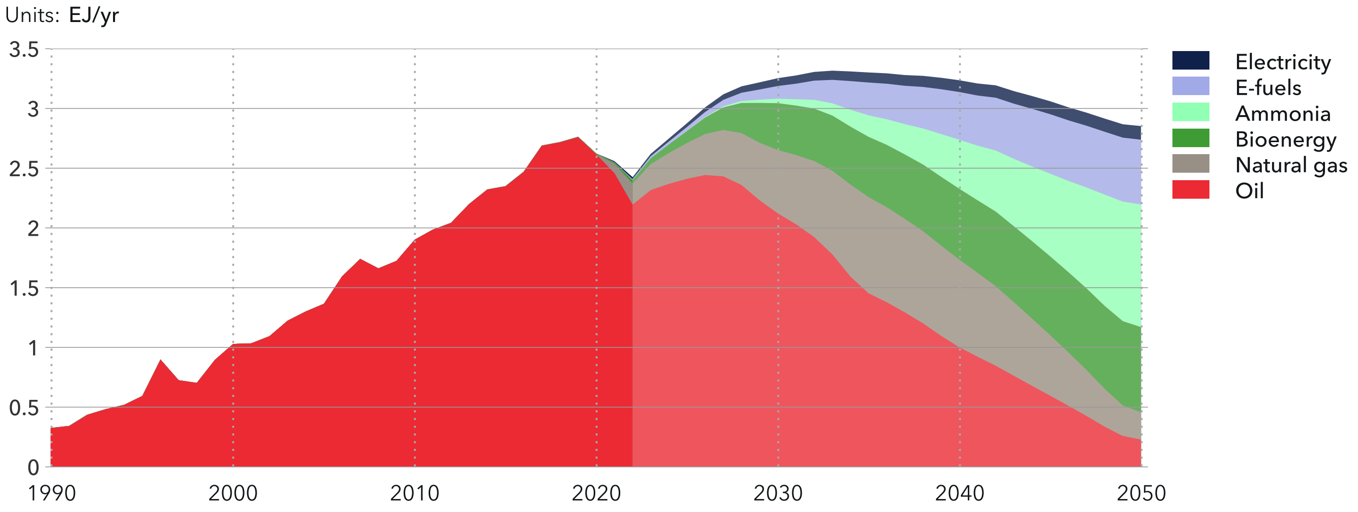
In pursuit of decarbonization, the shipping industry is particularly focused on addressing the challenge of securing a reliable supply of carbon-neutral fuels and establishing port infrastructure for their efficient delivery to ships. This concern stems from the industry's competition with other sectors for the limited supply of such fuels and the anticipated higher costs associated with carbon-neutral alternatives.

Shanghai International Port (Group) Co., Ltd. (SIPG), the main operator of the world's busiest container port is China's first and the world's third port able to provide ship-to-ship bonded LNG bunkering with simultaneous operations, registered LNG bunkering of over 260,000 cubic metres in 2023.

SIPG also commits to becoming a leader in developing green and ecological ports. SIPG signed a Memorandum of Understanding (MOU) with A.P. Moller-Maersk (Maersk) in March 2023 on strategic cooperation for Shanghai Port methanol marine fuel project. The two parties will join hands to explore green methanol fuel vessel-to-vessel bunkering operation after Maersk's green methanol container vessels being delivered in 2024. The agreement will also support the aspiration of Shanghai Port to become one of the world's first commercial green methanol bunkering ports.

FIGURE 3.5

Maritime energy demand by carrier



Historical data source: IEA WEB (2023)

The utilization of green methanol is a pivotal measure for the shipping sector to reduce emissions. Establishing a green methanol industrial chain is essential not only for shipping companies to align with the emerging trends of green, low-carbon, and intelligent shipping but also to provide customers with sustainable and eco-friendly global supply chain logistics services. Additionally, it represents a significant initiative in fostering green and low-carbon industries, steering the industry towards high-quality development.

Apart from advancements in technology, such as the introduction of new technologies, fuels, and operational measures, the successful reduction of carbon emissions in the shipping industry relies on the implementation of suitable laws and policies.

China's legal context of a multi-level regulatory system covers various aspects, including infrastructure, technology, organization, and governance, with specific focus on port shore power, ship power facilities, promotion of low-carbon ships and fuels, carbon emissions verification, and trading.

For example, the Chinese State Council issued the *Action Plan for Carbon Dioxide Peaking Before 2030* in 2021 which includes the commitment to work faster to upgrade old ships, develop ships fuelled by electric power and LNG, further promote the use of shore power by ships while in port, and make in-depth efforts to advance demonstration and utilization of green, smart ships along coastline and inland waterways according to local conditions. In parallel, China's Ministry of Transport published the development plans of both waterborne and green transportation for the *14th Five-year plan period (2021-2025)* separately in January 2022. In these development plans, the application of new and clean energy including methanol, hydrogen, ammonia, as well as the use of shore power in the shipping sector have been further encouraged and refined.

Beyond governmental and regulatory initiatives to decarbonize the maritime sector, the crucial factor enabling the adoption of zero-emission shipping services lies in the response to decarbonization requirements from cargo owners. This, in turn, creates a market demand for sustainable biofuels in the short term. Our recently published white paper, titled *Biofuels in Shipping*, provides insights into key aspects such as biomass availability, biofuel refinery capacity, and the compatibility of ships and engines with biofuel use (DNV, 2023c).

The successful reduction of carbon emissions in the shipping industry relies on the implementation of suitable laws and policies.

A notable and emerging trend we are currently witnessing involves certain cargo owners establishing ambitious decarbonization objectives for their operations. Achieving these targets, particularly in the reduction of so-called Scope 3 emissions related to cargo transportation, hinges on securing access to low- and zero-emission shipping services. In response to this demand, shipping companies have already initiated the provision of 'zero-emission services', and we anticipate a further expansion of this sector to meet the requirements of cargo owners.

As described, the maritime sector's approach to decarbonization has rapidly evolved, driven by the International Maritime Organization's (IMO) strategy introduced in 2018 and revised in 2023. The industry is shifting its mindset to contribute to the net-zero challenge, leading to a substantial change in fuel composition by 2050. We forecast that 84% of the composition will consist of low- and/or zero-carbon fuels, with ammonia, biofuel, and e-fuels commanding significant shares. Regional decarbonization initiatives will further support this shift.

However, uncertainties, including biofuel availability and renewable hydrogen for e-fuels, are outlined in DNV's 2022 *Maritime Forecast to 2050.* The 2023 forecast, influenced by the updated IMO strategy and external pressures, anticipates a more decarbonized fuel mix. Yet, it recognizes challenges due to the lack of enforcement mechanisms for IMO ambitions, emphasizing the need for ship-specific regulations. The fuel mix forecast in Figure 3.5 is based on expert assessment, acknowledging significant uncertainties detailed in DNV's *Maritime Forecast to 2050.*

Aviation

Civil aviation is one of China's fastest-growing sectors, playing a crucial role in global interconnectedness. Additionally, commercial aviation has significantly contributed to China's economic progress. With a flourishing middle class, an increasing number of Chinese citizens are opting for air travel, resulting in China's airlines and airports ranking among the busiest globally in recent years.

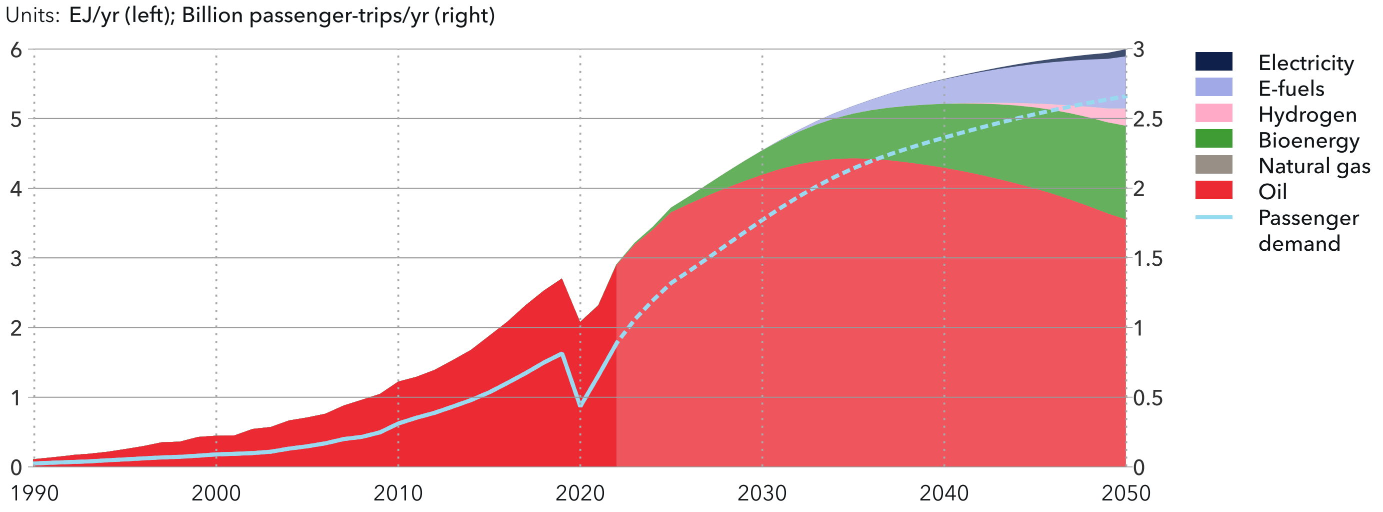
We forecast a continued notable uptick, projecting passenger trips to triple between 2022 and 2050, reaching 2.7 billion by mid-century. The increase in air travel is propelled by increased income levels, a growing willingness to travel, and ongoing rapid urbanization. With more civil transport airports anticipated, totalling 270 by 2025, and an increasing number of international flight routes, the industry is poised to accommodate this heightened demand. However, this figure remains modest when compared with larger countries, such as the United States and Brazil. A well-developed rail network is the key driver for this.

Essential initiatives implemented at airports, airlines, and infrastructure have helped to reduce emissions from aviation activities. This includes advocating the adoption of Ground Power Units (GPUs) instead of aircraft-based Auxiliary Power Units (APUs) at airports with an annual passenger count of 5 million or more. Furthermore, there has been the introduction of over 1000 new-energy ground vehicles at airports, a measure aimed at reducing carbon footprint. Efforts have also been made to decrease aircraft taxiing time, achieving an average reduction of three minutes. Additionally, a strategy involving the phased retirement of ageing aircraft has been implemented. These multifaceted initiatives collectively contribute to China's endeavours in managing and mitigating emissions in the aviation sector. Aviation sector emissions by 2050 will be only 17% higher than 2023, despite a tripling of passenger-flights, while the world as a whole grows aviation sector emissions by just 8%.

However, the biggest impact on emission reduction will come from a comprehensive fuel switch to low-carbon fuels. In 2022, 99.6% of aviation's energy demand was met by oil, with the remaining being biofuel. We will see oil continue to dominate the energy mix by mid-century, with its absolute use growing 30% while its share declines to 59%. The remainder of aviation's energy demand is met by bioenergy (22%), e-fuels (13%), hydrogen (4%), and electricity (2%). China's fuel mix closely resembles the global mix, where oil will have a 60% share. Given the far-reaching policies China has implemented in various sectors to reduce energy dependence, this might be quite surprising. However, aviation is one of the sectors where decarbonization is hardest due to, for example, technical limitations of peak power to be supplied from batteries, but also availability of drop-in fuels such as sustainable aviation fuels. We have commented on this in more detail in our 2023 *Transport in Transition Report* (DNV, 2023d)

FIGURE 3.6

Aviation energy demand by carrier and passenger demand



Historical data source: IEA WEB (2023)

Rail

China's rail progression over the last decade and continued expansions position trains as a competitive, low-carbon alternative to short-haul flights. By further establishing high-speed rail as an integral part of the country's sustainable and efficient transportation system, China will see improved mobility access, which will enable a modal shift and meet the increasing passenger demand. As illustrated in Figure 3.7, an almost twofold growth in passenger numbers between 2022 and 2050 is anticipated, propelled by increasing living standards and urbanization. We also foresee a doubling in freight demand over the next three decades. High-speed trains in China offer advantages such as cost-effectiveness, punctuality, and time efficiency, making them an appealing choice for consumers.

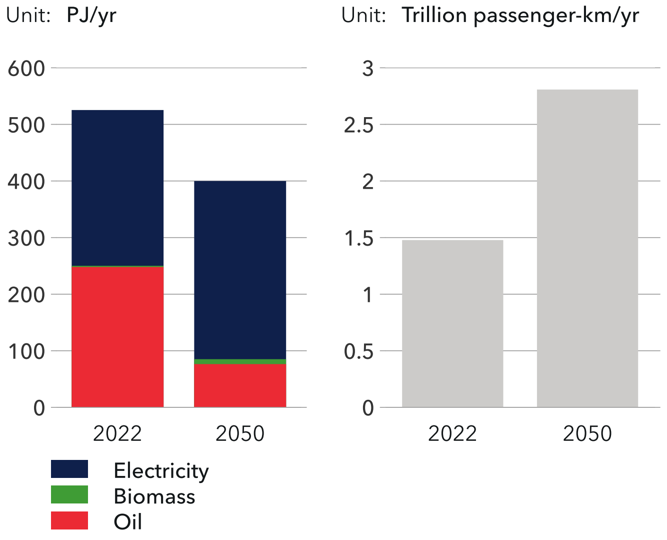
By a considerable margin, the second-most populous nation boasts the largest high-speed railway network globally. A vast expanse of 37,900 kilometres of railway lines connects its major mega-city clusters. Notably, all these lines have been constructed since 2008, and half of the total length has been added in just the last five years. There are ambitious plans for the network's expansion, with expectations that its length will double once again, reaching 70,000 kilometres by the year 2035. Expansions are also to be seen for the urban rail network, increasing from 6,600 km to 10,000 km by 2025.

Rail's energy demand is forecast to decline 24%, from 525 PJ/yr in 2022 to 400 PJ/yr in 2050, and we see significant expansions and electrification for the Chinese rail network in the near future.

Rail's suitability for electrification further positions it as an attractive choice for transport decarbonization and energy-efficiency advancements. From its already high share of 52% in 2022, electricity's share in rail energy demand is expected to increase to 79% by 2050.

FIGURE 3.7

Rail energy demand by carrier and passenger trips

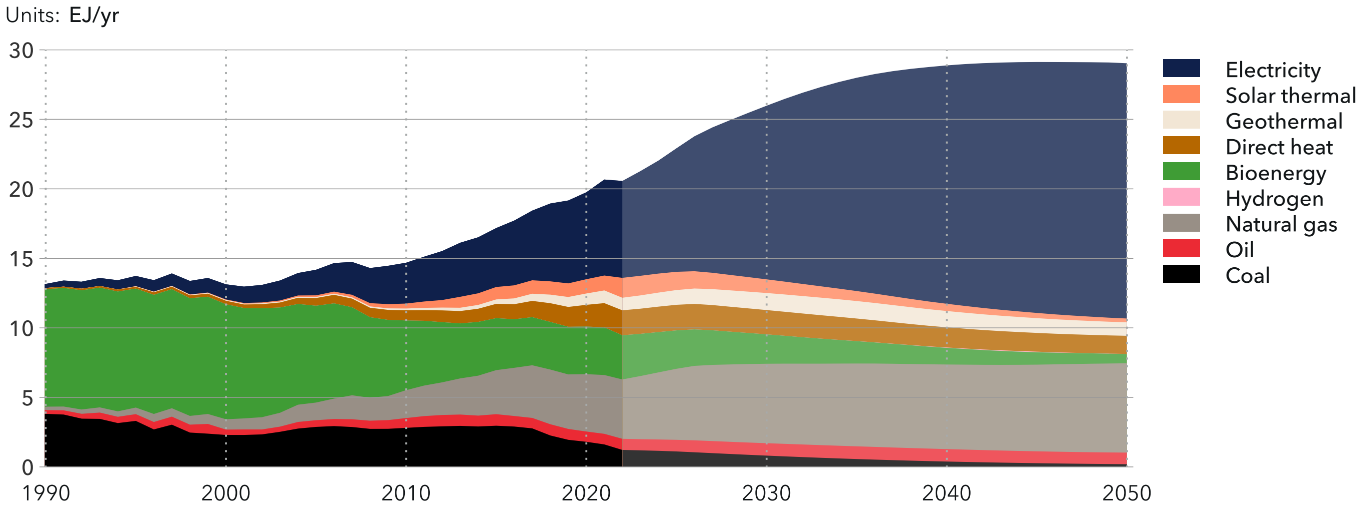


3.2 Buildings

In buildings, electricity expands from 34% of the mix today to 63% in 2050. Total energy demand is set to grow over 40%, with the floor area of the buildings stock in China rising 49% to over 100,000 km² by 2050. Retrofitting buildings and improving insulation will be key to improving energy efficiency and lowering emissions.

FIGURE 3.8

Buildings energy demand by carrier

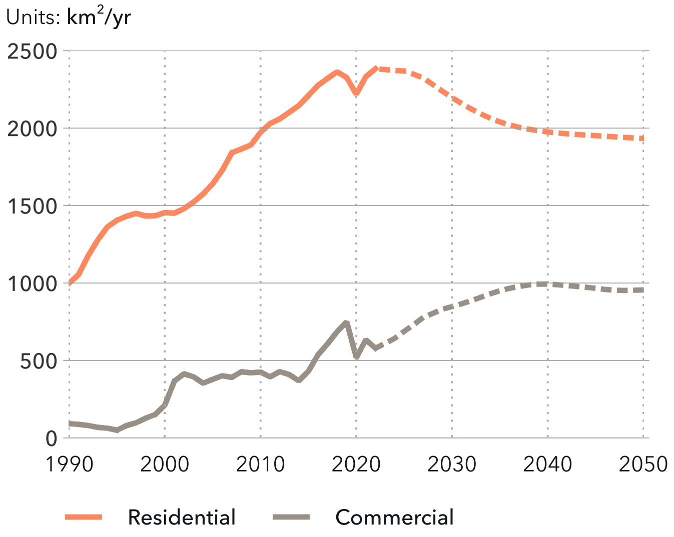


China has prioritized energy saving in buildings and green building development in their *14th Five-year plan*. While there will be improvements in energy efficiency, insulation, and heating/cooling equipment, buildings energy demand and floor area are still set to increase. Though the region's population has peaked, GDP continues to rise. Driven by this increase, the floor area of residential buildings rises by 28%, and commercial buildings' floor area rises by 157% by 2050. Buildings' energy demand in China is set to grow over 40% between now and 2050, peaking in 2045 before declining slightly to come to rest at 29 EJ in 2050 – almost one-fifth of global buildings' energy use (Figure 3.8). The share of buildings' energy demand in final energy is also set to increase from 19% to 28% in 2050 due to both this growth of floor space and the shrinking of energy demand in the manufacturing sector and the inroads made by more efficient electricity there.

The buildings sector is split into residential and commercial properties in our model. Presently, about 80% of energy is consumed by residential buildings. This drops slightly to 70% in 2050 due to faster growth in GDP than in population, where the 29 EJ sectoral demand in 2050 will be split into 20 EJ residential and 9 EJ commercial. Electricity grows to be the dominant energy carrier, expanding from 34% of the mix today to 63% in 2050. Oil, biomass, and coal decline to negligible levels, though we still see a fair amount of natural gas – 22% of the mix in 2050 – due to the prevalence of this energy carrier in gas boilers for space heating and cooking equipment. Emissions for this sector are relatively low, at 0.42 $GtCO_2$ in 2022, declining to 0.40 $GtCO_2$ in 2050 – only 10% of China's total 2050 energy-related and process emissions.

FIGURE 3.9

Residential and commercial buildings additions



Building stock

The growth in floor area is one of the main drivers of buildings energy demand. By 2050, the floor area of the buildings stock in China will be over 100,000 km², around the size of Iceland, and making up about a quarter of the world's floor area, with growth driven primarily by GDP. China is currently facing industry-wide challenges in the buildings industry, particularly residential buildings, with weak demand fuelling oversupply and capital issues (Kelter, 2023). The current crisis is likely to be eased in the medium term by a range of government policies designed to ease restrictions on residential purchases and stimulate home completions – along with lower interest rates insofar as the dollar to yuan exchange rate allows that. However, the present distress in the construction industry does foreshadow a longer-term slowdown in building sector demand across China. The country's largest construction company, Evergrande Group, defaulted in late 2021, has filed for bankruptcy protection in the US, and is now facing liquidation. It is not alone; many building companies are struggling financially with high debt and leaving buildings unfinished (Stevenson, 2023). We see this in residential buildings additions, where they will decline and generally level out by the end of the 2030s, while commercial buildings additions will grow steadily until this time and then plateau (Figure 3.9).

Retrofitting buildings and improving insulation will be key to improving energy efficiency and lowering emissions. As previously mentioned, China has mandated urban regeneration in its *14th Five-year plan*, ending the cycle of demolishing and rebuilding, and instead focusing on energy-saving renovations. As of 2021, China has made the retrofitting of old buildings in the north a priority, intending to complete energy-efficiency renovations for more than 350 million square metres by 2025. There is also legislation around the efficiency of new residential buildings, which in the north of China must on average run on 75% less energy than a new building in 1980 (Zhijian, 2023b). We see this legislation broadly achieving its aims, with the u-value (a measure of thermal transmittance, or the rate of heat transfer through matter) of both residential and commercial buildings dropping by around 15% by 2050.

Space Cooling

The need for space cooling increases the most among all the energy end uses, rising from 7% of the mix to 29% in 2050. This will be split around 80:20 between residential and commercial space. There are two drivers of this increase: Firstly, the demand for cooling rises with GDP as more people can afford the technology. Secondly, the effects of climate change; a study from Tsinghua University predicts that heatwave days in 74 key cities will increase from 2.7 to 8.8 per year (Zhijian, 2023c).

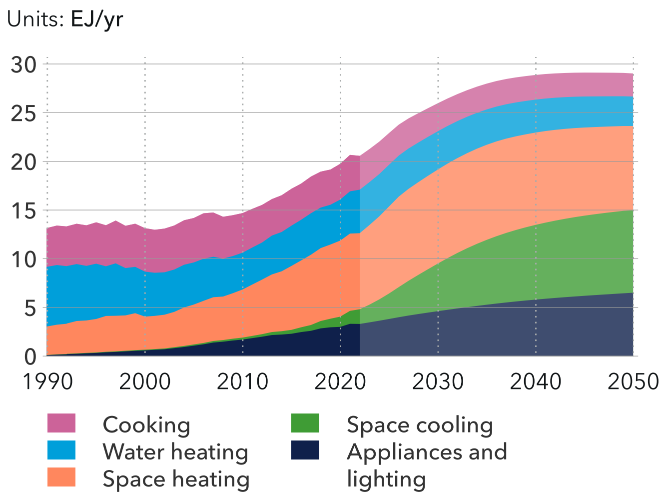
We measure the effect of increasing world temperatures through the rise in cooling-degree days. In 2022 these stood at 519°C-days/year in China, by 2050 they will have increased over 40% to 742°C-days/year. Insulation plays a significant role in lowering space cooling energy demand; without improvements over time, the space cooling demand in 2050 would be around 20% higher. In 2050, China will use a little over 30% of the world's total cooling energy, around 8.5 EJ (Figure 3.10).

Cooking

In cooking, we see the results of both efficiency improvements and access to modern cooking. By 2050 households without access to modern cooking will drop from 21% today to nearly zero in 2050. Biomass makes up the largest part of cooking energy demand today at 56% of the mix. By 2050, this will be overtaken by natural gas at 57%, while modern biomass will come in at 21%, and electricity, favoured by the younger generations, will make up 19% of the mix. Both electricity and natural gas are far more efficient for cooking than biomass. We see the effects of this efficiency improvement in the end-use mix, where cooking's share decreases from 17% to 8% in 2050. Cooking energy use in China in 2050 will be 2400 PJ/yr (Figure 3.10).

FIGURE 3.10

Buildings energy demand by end-use



Historical data source: IEA (2023), EIA RECS (2020), DNV analysis

Appliances and Lighting

In our model, demand for energy for appliances and lighting is driven by the share of the tertiary sector in GDP, while also accounting for energy efficiency improvements over time. With China's tertiary sector set to grow from 53% of GDP to 72% by 2050, we will see energy use for appliances and lighting double in terms of energy used (6,550 PJ/yr in 2050), rising from 16% of the mix to 23% by 2050 (Figure 3.10). Electricity is naturally the only energy carrier in this sector. Demand for appliances, especially smart appliances, is already on the rise and is only projected to grow. China is already the largest consumer market of smart home devices.

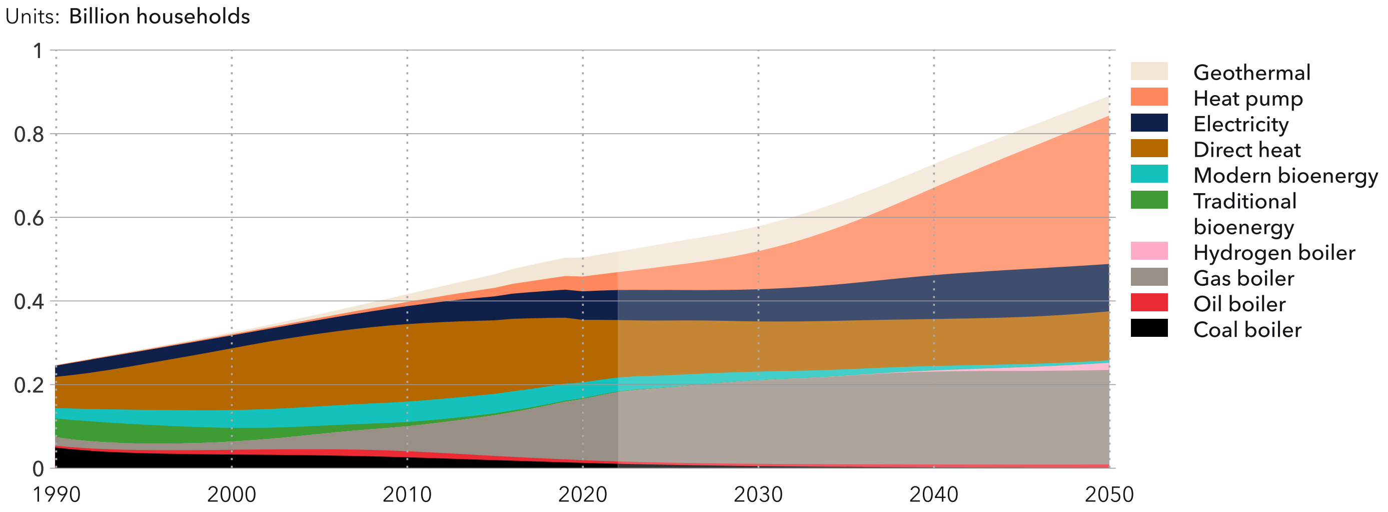
> Insulation plays a significant role in lowering space cooling energy demand; without improvements over time, the space cooling demand in 2050 would be around 20% higher.

Space Heating

Space heating declines from 38% of the mix today to 30% in 2050 as improvements in energy efficiency will outweigh much of the growing demand for energy. This trend is also aided by fewer heating degree days towards 2050. In 2050, space heating will use 8,600 PJ/yr (Figure 3.10). There will be an uptick in electricity as an energy carrier, from 17% of the mix today to 24% in 2050. The major driver of this increase is the rise of heat pumps. Their inclusion in the space heating technologies mix is one of the biggest changes we see in buildings in China towards 2050. Today, heat pumps make up about 8% of the technology mix, but by 2050 this will rise to almost 39%. They will be used both in new buildings and to replace fossil fuel boilers. At present, China is already leading the world in new sales for heat pumps, along with patenting, manufacturing and installation; with over 12 million air source heat pumps installed today (Rudgard, 2022), and we see this trend continuing. The technology is well suited to the south of the country, where it is used both to heat residences in the winter and cool them in the summer. Other regions in China have different economic levels, climates, resources, and infrastructure, so heat pumps are not a 'one size fits all' solution to heating energy demand. Gas boilers (25%), direct heat (13%), and conventional electricity (12%) are the other prominent technologies used for space heating in 2050 (Figure 3.11).

FIGURE 3.11

Households by space heating technology



3.3 Manufacturing

Manufacturing was China's largest consumer of energy in 2022, accounting for over 50% (56 EJ) of the final energy demand. China has historically been a manufacturing powerhouse, making up a large global share of key industries like iron and steel, cement, manufactured goods, and base materials. While coal will more than halve in China’s manufacturing energy mix by 2050, manufacturing in China will still use more coal than the rest of the world combined.

The locus of global manufacturing

Industrial development has been the key driver for the rise of China in the last two decades and has supported both domestic and international development. This capacity has led to the moniker 'factory of the world', which is inseparable from China’s global influence. Over 40% of global manufacturing energy demand is concentrated in China, which has doubled over the last 20 years. After this period of rapid, energy-intensive growth, manufacturing in China is gradually shifting focus to improving energy efficiency (Institute of Climate Change and Sustainable Development of Tsinghua University, 2022).

Heavy industries have been the backbone of Chinese development, but manufacturing in China is an evolving sector. This is reflected in the shifting of industrial economic activities from energy-intensive, low-value added products like steel, building materials, and textiles to more high-tech, advanced manufacturing.

Industrial strategy is guided by the central government’s Five-year plans, which are supported by policies and implementation plans from the National Development and Reform Commission (NDRC) in China’s '1+N' policy framework. This framework is supported by province and city-level action plans. The broader policy goal stated in the *14th Five-year plan* is to build up industry in provinces in central and western China, as current production is focused in the eastern and coastal provinces, which are more developed and populated.

Central policies have a very strong influence. One of the most recent striking examples is the supply-side reform policy implemented in the late 2010s. In 2015, overcapacity problems became clearer in some sectors. The most polluting, less energy-efficient plants were forced to reduce production or close down, as part of overall policy aims to shift economic activities from energy-intensive industry to other sectors. The policy-driven shift led to a significant decrease in coal growth in the 2010s, after the global peak coal consumption in 2014. The compound annual growth rate for coal between 2000 and 2009 was around 10%, dropping to just 1.3% in the following decade.

Although policy is driven by the vision of the central government’s Five-year plans, the provinces have significant freedom to create their own policies to reach the targets. These consist of binding targets for both energy and emissions efficiency per unit of GDP. There is domestic competition between the provinces to keep industries locally in the province to support the tax base, and growth and subsidies are the provinces’ responsibilities. An example is Anhui province’s big investment in EV startup NIO, where subsidies were used to attract the company to relocate to Anhui’s capital Hefei (Mazzocco, 2020). The state is responsible for consumption and emission reduction, but this can be difficult for Beijing to implement as provinces and industries are reluctant to cut jobs and tax revenues.

King coal will progressively lose ground

The growth in manufacturing has historically been supported by intensive coal use. As shown in Figure 3.12, more than 80% of manufacturing energy has been provided by coal in the last two decades if accounting for both direct and indirect energy use. The share of coal is now progressively declining, as heavy industries become less important and other production is increasing. Coal use will fall to about a third of manufacturing demand to 2050.

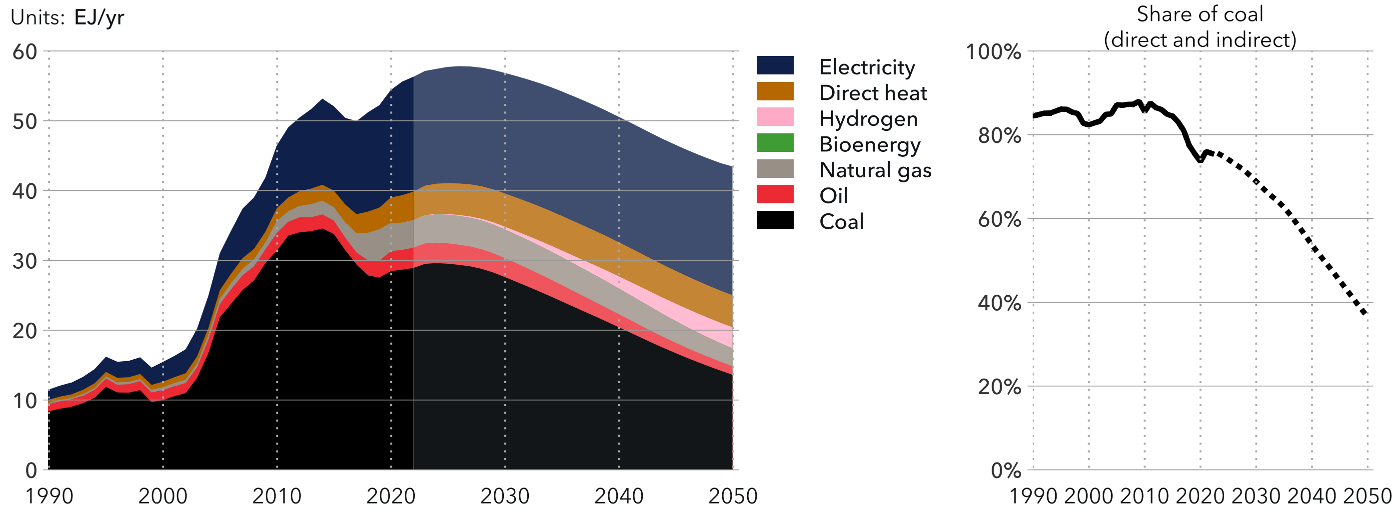
Declining emissions with little help from CCS

Manufacturing is responsible for around a third of China’s emissions today. As processes become more energy-efficient, coal is phased down, and electricity takes an increasing share, emissions will progressively reduce. As shown in Figure 3.13, although manufacturing emissions will almost halve by 2050, they will decrease at a slower pace than the rest of the energy system. Despite large emission reductions, manufacturing will remain responsible for half of China’s emissions in 2050.

CCS is not expected to play a huge role in the decarbonization of manufacturing in China in the short term. CCS is not a high priority in policy planning as there are fewer opportunities for commercialization and thus there are no concrete measures for CCS. However, some research mandates have been issued for state-owned enterprises

FIGURE 3.12

Manufacturing energy demand by carrier



Historical data source: IEA WEB (2023)

Indirect use includes electricity and direct heat production.

(SOEs) in northern provinces where heavy industry is concentrated. Most of the manufacturing capacity will be installed in ammonia production, where costs are lowest. About 100 $MtCO_2$/yr will be captured by 2050, covering about 5% of manufacturing emissions.

Heavy industries dominate in energy use

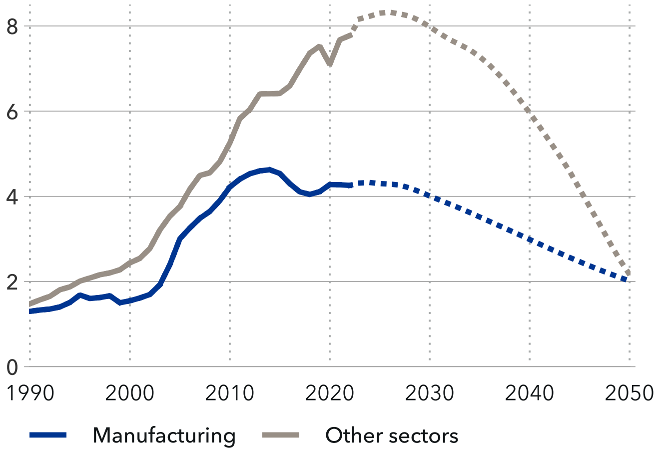
The explosion of manufacturing energy demand in the last two decades has been supported by the boom in the construction of buildings and infrastructure, which significantly raised the demand for energy-intensive products like steel and cement. Together, these two industries account for half of China's manufacturing energy demand today, and around a quarter of the country's total energy demand. Steel and cement are likely to be the first manufacturing subsectors to join an ETS scheme in China.

Demand for these products is highly reliant on the economic situation. As a result, China has had chronic overcapacity issues in these industries which were solved by tough policies like the supply-side reform in 2015. The recent downturn in the real estate market has, for the moment, been compensated by a strong demand for infrastructure, but we forecast a progressive decline in demand by 2050. However, the inertia of newly installed and planned capacity additions will keep China at a very high level of production. We expect short-term overcapacity issues to be solved through air pollution measures, which are forcing the worst performing installations out of cities, without necessarily replacing the lost production capacity elsewhere.

FIGURE 3.13

Manufacturing CO_2 emissions

Units: $GtCO_2$/yr



Manufacturing emissions include energy and industrial process emissions

Iron and steel production is increasingly concentrated in China. Second only to power, iron and steel production is the second highest emitter in China and is highly dependent on coal and coal products.

China is the largest consumer of steel and, since 2018, has produced over half of the world's steel, over 90% of which is produced via energy-intensive blast furnaces and basic oxygen furnaces (BOF). Steel production in China is mostly state-owned and production is decentralized, where the top three producers accounted for only 22% of annual crude steel production in 2022, shown in Figure 3.14. Transitioning to electric arc furnaces (EAF) drastically reduces emissions and energy usage, as it primarily uses scrap steel rather than virgin steel in production. However, many BOF facilities in China are somewhat new, making the transition to EAF less economically appealing (Sandalow et al., 2019).

China's iron and steel plants are often located in provinces with rich iron ore and coal resources, such as Hebei, Liaoning, Shanxi, and Inner Mongolia, and in coastal regions that have a higher demand for steel products.

Cement production and consumption in China accounts for more than half of the global total. The cement industry is highly dependent on fossil fuels and accounts for approximately 11% of China's carbon emissions. It is the third highest emitter, after power and steel. An estimated 90% of cement production facilities in China were built in the last 20 years and 40% in the last 10 years (RMI & China Cement Association, 2022). This is reflective of rapid development both domestically and internationally, particularly urbanization in the past two decades in middle-income countries like China, Indonesia, and Brazil. Energy demand for cement more than doubled from about 2,500 PJ/yr in 2000 to over 5,600 PJ/yr in the 2014 peak. We forecast the energy demand for cement to slowly decline to around 3,000 PJ/yr in 2050 due to factors such as slowing urbanization and improvements in build-material efficiency.

The cement industry in China is characterized by a low market concentration rate among top cement companies, where the top 10 clinker producers account for approximately 55% of total production capacity. Low centralization hinders the large-scale proliferation of new technologies, which could improve efficiency and decrease carbon emissions. An example is the use of alternative fuels rather than coal for clinker sintering, which accounts for around 90% of total cement production emissions. In 2018, alternative fuels accounted for less than 2% of energy consumption per tonne of clinker in China, compared to 14% in the US and over 43% in Europe (RMI & China Cement Association, 2022). The use of alternative fuels or electrification to replace coal in the cement industry is expected to increase, in line with the *14th Five-year plan's* goals to control coal consumption in major coal-using industries and to promote energy savings and carbon reduction.

TABLE 3.1

Top producers in China in 2022

Crude steel (by production)	Cement (by annual production capacity)	Aluminium
Baowu*	China National Building Material (CNBM)*	Chinalco*
Ansteel*	Anhui Conch	Hongqiao Group
Shagang Group	Jidong Cement*	Xinfa

*Indicates enterprises that are fully or majority state-owned.

Energy use in the **base materials** subsector in China is dominated by non-metallic minerals and non-ferrous metals production. The energy-intensive aluminium production is the largest contributor among them. Primary aluminium production has risen steadily from 3 Mt/yr in 2000 to 40 Mt/yr in 2022, making China the largest producer by far, with 60% of global primary production (IAI, 2023).

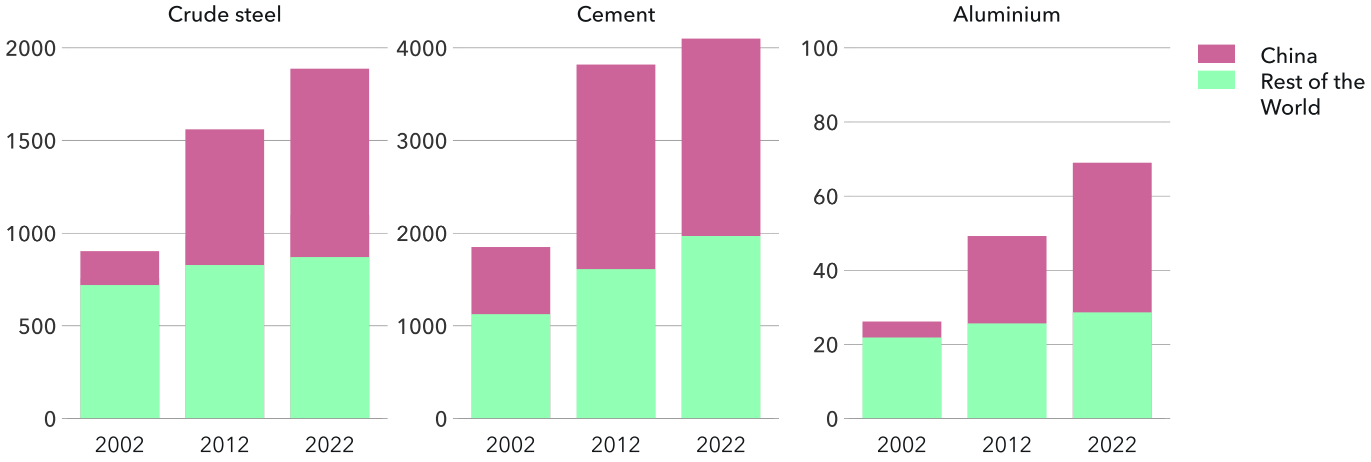
Although roughly a quarter of the production is currently exported, with the US being the first export market, the increasing production is supported by an increasing domestic demand. Aluminium is an essential material for the energy transition, especially for its lightweight properties (e.g. for cars and solar panels). However current production is close to the ceiling imposed under the supply-side reform policy, meaning that domestic production will stagnate. Although China is one of the largest bauxite producers (the raw mineral for aluminium production), it still needs to import more than half of its needs and outsourcing some of the capacity abroad (Indonesia) is seen as an option. China will also have a growing energy-efficient recycled aluminium production (requiring about 5% of the energy use of primary production).

Coal and electricity have dominated the fuel mix. This will be one of the main drivers for a decreasing energy use in the base materials and a growing share of electricity in the fuel mix. Figure 3.15 shows the energy demand for each of the manufacturing subsectors.

FIGURE 3.14

Production share of key manufacturing areas

Units: Mt/yr



Data source: Worldsteel (2023); Reuters (2013); Otto et al. (2017)

Data source: Statista (2023); USGS (2023)

Data source: International Aluminium (2023)

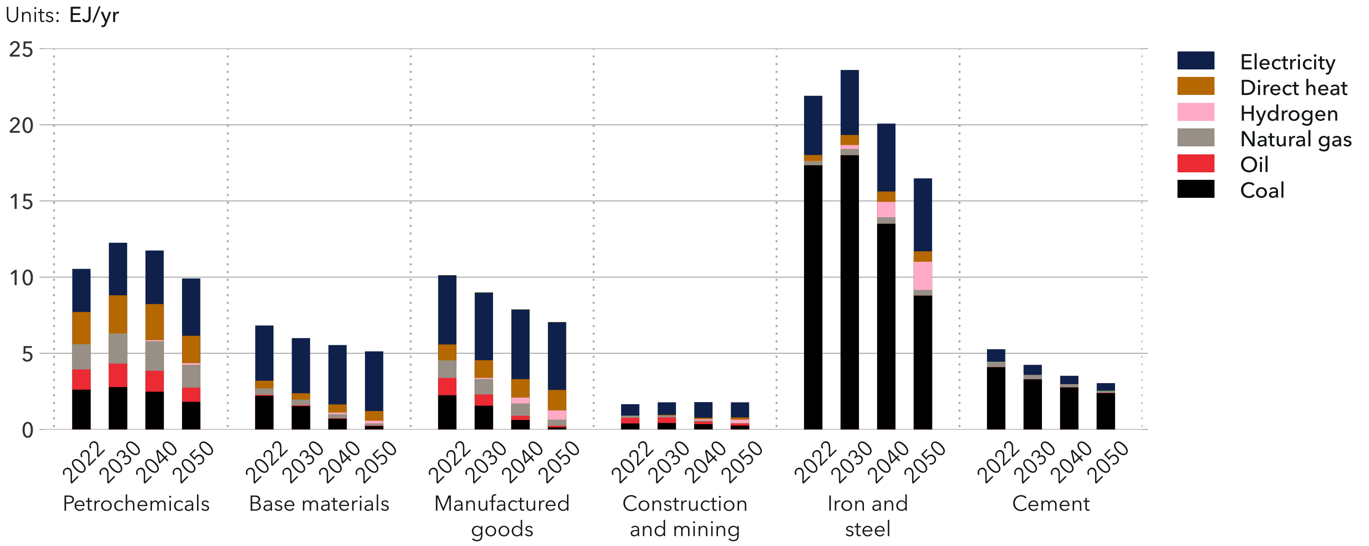
In **construction and mining**, state decarbonization plans are contributing to the growing demand for battery- and hydrogen-powered heavy equipment. Chinese manufacturers, such as the state-owned Xuzhou Construction Machinery Group, aim to increase the uptake of battery-supported and fully electric heavy trucks and equipment, mirroring the overall trend of electrification in transport and manufacturing.

Whilst energy demand will operate a decline in most subsectors, **chemicals and petrochemicals** production will continue to increase, driving an average 2%/yr growth in energy demand to 2030, then reaching a plateau in the 2030s. The subsector development is essential in reaching China's self-sufficiency goal. China is home to a large share of today's chemical market and has built its industry first around coal and is now importing increasing amounts of crude oil, as discussed in Section 3.4.

The **manufactured goods** subsector is where most of value added and export value is created, especially given that China is turning to higher value-added products, notably related to the energy transition (see Factbox). Lower-value added industries are also relocating to other countries. In this subsector, temperature needs are usually lower and more efficient electrified processes are often available. That is why even though manufacturing value-added (MVA) will increase, we forecast a decrease in energy use.

FIGURE 3.15

Manufacturing energy demand by subsector and energy carrier



A global centre for clean technologies

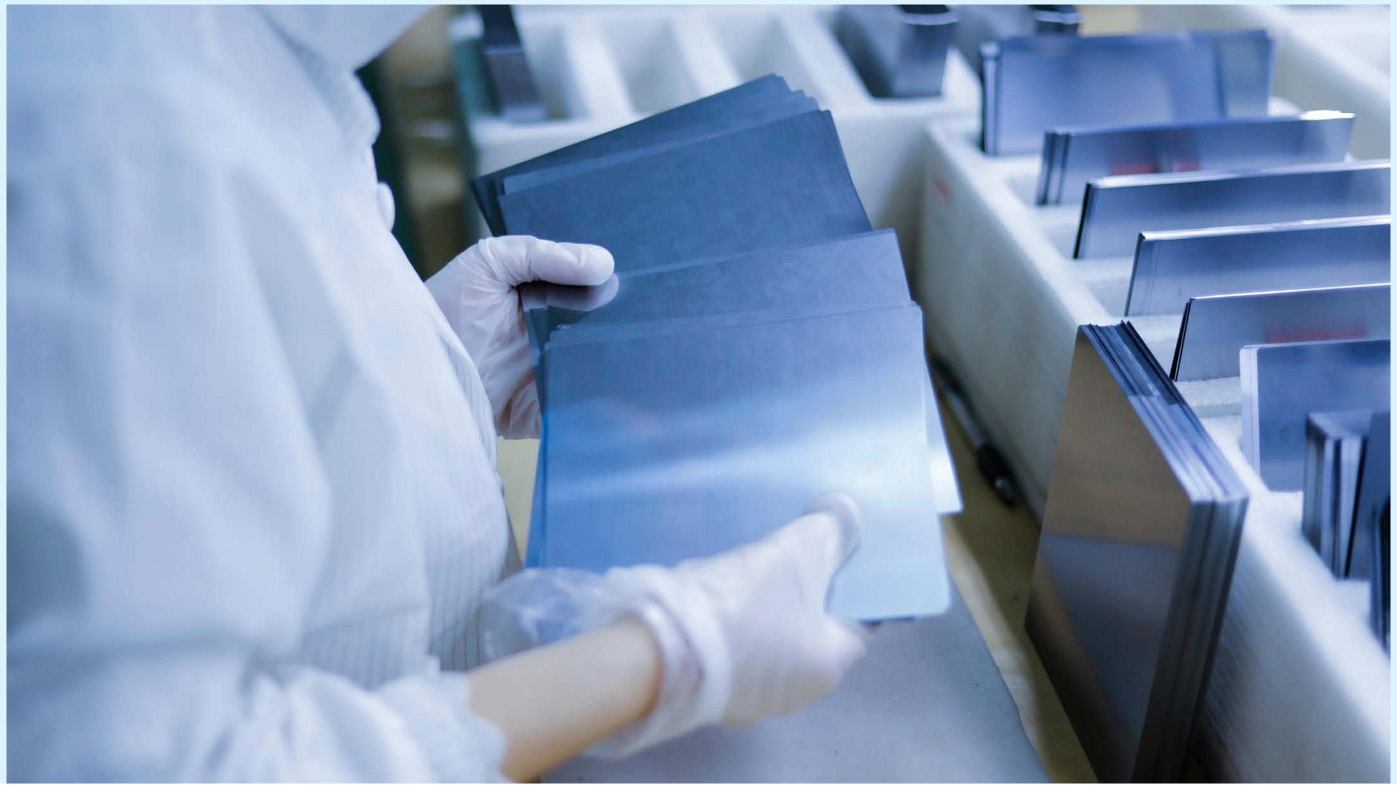
China has become essential in the manufacturing and development of key technologies for the energy transition. It is impossible to dissociate China from the dramatic growth in production and related reduction of costs in clean-energy technologies.

In 2022, China accounted for more than 80% of the global solar cell exports, more than 50% of lithium-ion batteries and more than 20% of electric vehicles (You, 2023). China is also emerging as a dominant player in global wind power generation, with the country's manufacturers supplying nearly 60% of installed capacity worldwide in 2022.

The development in cleantech industries is also supported by an oversupply of skilled workers attracted to the booming EV and solar panel industries. These industries are regularly ranked among the most attractive by fresh graduates, competing with the popular but increasingly regulated IT sector (People's Daily Online, 2019).

When it comes to the semiconductor industry, China still faces challenges in achieving self-sufficiency. Because semiconductor fabrication processes require intensive R&D, staying at the forefront demands significant investment and a highly skilled workforce. Many cutting-edge semiconductor technologies are patented and guarded by multinational corporations, making access to these technologies a complex endeavour for Chinese companies. Additionally, certain key materials and equipment in semiconductor manufacturing are essential and often sourced from foreign suppliers (Vyrian, 2023).

The US has imposed export controls and sanctions on Chinese semiconductor-related companies, limiting their access to certain technologies and components. Similarly, Beijing has revised export/import guidelines to restrict the export of solar panel equipment (though not the panels themselves) (Lee, 2023). However, the domination of China in a significant number of steps of the cleantech supply chains and the slow progress in increasing production in other regions (IEA, 2023a) means that China will remain a key player in this field for the coming decade.



3.4 Non-energy demand

China is the largest producer and consumer of chemical products, leading to increasing global influence in the sector. Demand for chemicals is increasing and is expected to continue increasing until 2050, also driven by the energy transition.

As in the rest of its industry sector, China has developed and is still developing a chemical industry at an impressive pace. This is the main factor explaining the historical and future growth in non-energy demand shown in Figure 3.16. To support this growth, China has chosen a rather distinctive path relative to other large chemical producers.

Domestic supply via coal-based chemicals

A major difference was the early and massive use of coal as a primary feedstock, as it is abundant, cheap, and available domestically. Coal, alongside petcoke (a by-product of oil refining), is mainly used to produce the base chemicals ammonia and methanol, for which China has become the world's largest producer. Coal's primacy is evident in methanol production, where over 75% of methanol produced in China comes from coal, compared to the global average of 8% (Li et al., 2022).

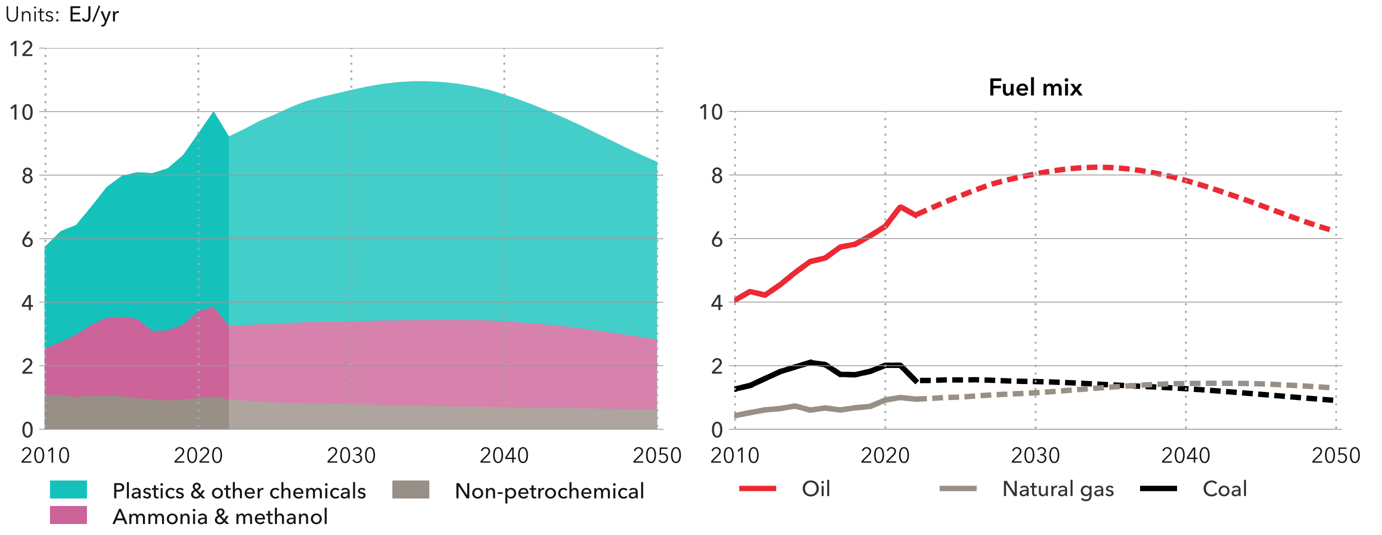
Demand for ammonia as feedstock (for fertilizer or chemicals) is forecast to remain relatively stable at around 55 MtNH$_3$/yr from today until 2050. Decreased demand for agricultural ammonia, due to improved fertilizer utilization, is likely to be compensated by increased ammonia use in the chemical industry.

Despite China using increasingly more natural gas as an alternative, and although coal-based processes are much more emission-intensive than natural gas-based processes, coal-based chemicals production will remain strong. These are often considered by the authorities as a more efficient and less emissions-intensive alternative to using coal for power production. Coal-to-chemical production plants are also concentrated in provinces with easy access to coal resources, like Shanxi and Shaanxi in the northwest, and these provinces have a strong interest in defending their local industries.

That is why we are forecasting a continued use of coal in the next decades, only decreasing after 2030 to 60% of today's level by 2050. Many of the existing production assets are young, so retrofitting facilities with CCS is the cost-efficient route for low-carbon production. The concentrated CO$_2$ from the coal gasification makes capture easier, and as levelized costs converge, our forecast sees a significant uptake of CCS, covering 30% of hydrogen production for ammonia and methanol feedstock by 2050.

FIGURE 3.16

Non-energy demand for energy carriers by end use



A growing oil-based industry

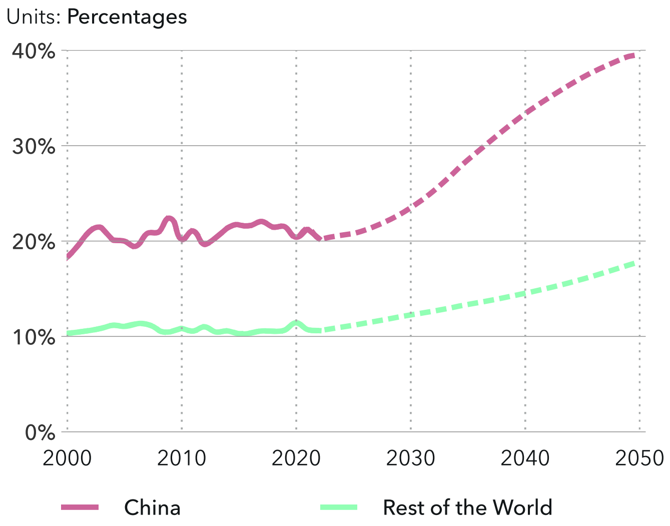
Most of the growth in non-energy demand will continue to come from the production of plastics and other chemicals. Demand is on the rise for these products, first and foremost to support domestic demand. The feedstock depends on local availability and prices, but oil-based naphtha is now dominating and will be supporting future growth.

Oil-based petrochemical production is mainly concentrated in two coastal provinces with different characteristics. Shandong is the biggest hub for refinery plants with proximity to oil resources, has easy access to trading routes, and enjoys a greater presence of SOEs than private enterprises. Zhejiang is developing its petrochemical industries by building its own refineries and transforming one of its ports with the goal of becoming a major hub for petrochemical import and export.

While there is no self-sufficiency target, the intention is to grow the industry and strengthen the domestic supply chain, which still relies on imports. For instance, China was the first importer of ethylene and its derivatives in 2022, which are essential building blocks for most plastics and chemicals (WITS, 2023). China's chemical industry is also currently grappling with an overcapacity of low-end products and an undersupply of high-end ones. (RMI, 2022).

FIGURE 3.17

Share of non-energy use in China and global oil demand



There are efforts underway to solve these issues. Chinese oil refiners and petrochemical companies, led by state oil giant Sinopec and others are, for example, investing heavily in the production of high-end chemicals for solar panels and batteries. This will also help achieve the 5% per annum growth target of its industrial value-added, a slightly lower value than for the batteries and renewables industry (8-10%).

As a result, while oil demand for energy purposes will peak before 2030, the demand for non-energy use will continue to increase in the coming decade. The share of non-energy use will double, representing around 40% of oil demand in 2050 as shown in Figure 3.17. In contrast, the share of non-energy use of oil in the rest of the world will increase slowly to 18% in 2050, less than half of that in China. Total demand for oil in non-energy use is forecast to decline from the 8 EJ/yr peak in the 2030s to around 6 EJ/yr in 2050. The decline is not because demand for plastics in particular will decrease, but because recycling rates, starting from a low 20% today, will steadily increase. Together, mechanical and chemical recycling will grow to cover around 70% of the waste stream by 2050.

4 ELECTRICITY AND HYDROGEN

Electricity, hydrogen, and hydrogen derivatives will reach a share of 53% of China's final energy demand by mid-century. The share of electricity alone in final demand rises from 25% at present to 47% by 2050, making China the second most electrified region in the world by mid-century. Well over 90% of electricity supplied in 2050 will be from non-fossil sources, thus playing a critical role in China's decarbonization journey.

By mid-century, China will have made great progress in electrifying all its major demand segments: buildings, manufacturing, and transport. China will use hydrogen and its derivatives in hard-to-electrify segments, such as maritime and aviation transport and high-heat manufacturing processes.

Electricity's share in final energy demand will grow from 25% in 2022 to 47% in 2050, aided by the extensive buildout of the regional grid. Of this relative growth, the majority will come from the rapid rise of renewables, particularly solar PV and onshore and offshore wind. This growth is aided by China's position as a clean tech leader and manufacturing powerhouse.

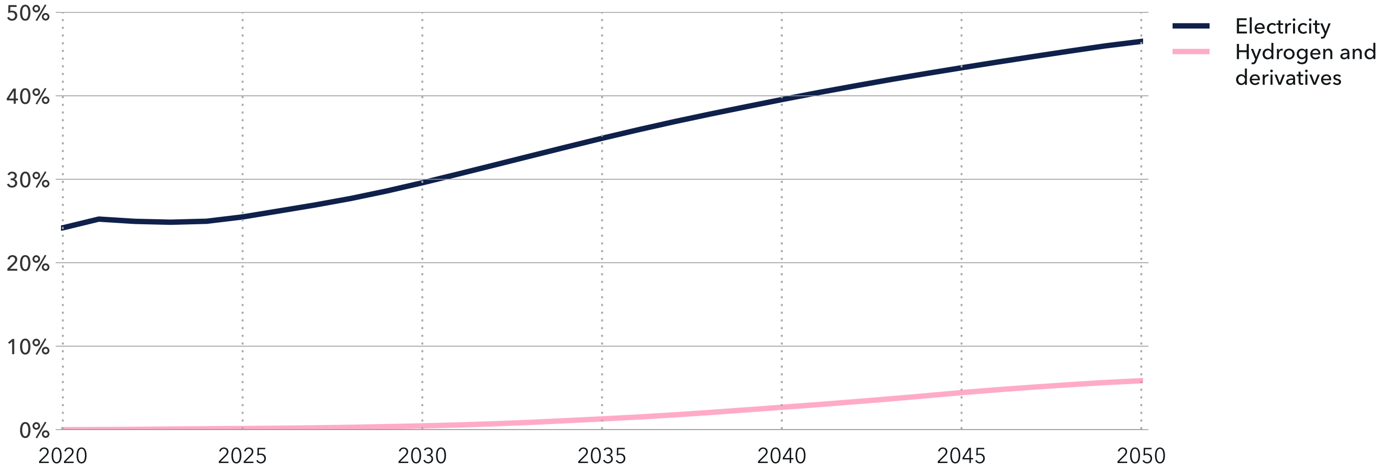
Hydrogen and its derivatives will play a relatively smaller, albeit important, part in China's energy system. China's ambitions for producing electrolysers, coupled with ample solar and wind resources, means that the majority of the hydrogen produced will be electrolysis-based. By 2050, the share of hydrogen and derivatives such as e-fuels and ammonia in China's final energy demand will reach 6%. This is slightly above the global average of 5%, but behind, for example, Europe where hydrogen and its derivatives will be catering to 13% of energy demand in that region by mid-century.

> Electricity and hydrogen are essential for the decarbonization ambitions of China, while reinforcing its market leadership in clean tech.

FIGURE 4.1

Electricity and hydrogen share in final energy demand

Units: Percentages



4.1 Electricity

Despite China progressing towards being among the most electrified of world regions by 2050, we note that electricity demand grows a mere 2% year-on-year from 2023 to mid-century, in contrast to 6% growth from 2010 to 2020. This slow-down is explained by a declining share of manufacturing in GDP, the leveling off of end-use electrification, and a decreasing population. The slower pace of electrification also brings about a re-ordering of priorities for the electricity sector, with far-reaching impacts on the rest of the world.

The three decades leading up to 2023 have seen great societal and structural upheavals in China. Increasing industrialization – and the accompanying growth in prosperity, urbanization, and electrification – and opening of the country to the global market economy all contributed to increasing electricity demand. To cater to this demand, the foremost priority was capacity expansion and electricity generation 'at least cost' (Glachant and Rossetto, 2022). This need for capacity and generation was not helped by the energy geography of this vast country, with its industrial demand centres located far away from both its renewable energy sources and fossil sources such as coal.

We foresee, and indeed are already witnessing, changing priorities when it comes to the electricity sector of China. The main reasons for changing priorities are:

- Declining growth of electricity demand and supply (Figure 4.2) due to restructuring of the economy and declining population
- Climate and decarbonization goals and local air-pollution mitigation
- Ever increasing need for energy security in a multi-polar world
- Strong desire to consolidate its leadership position as a clean energy technology powerhouse amidst mounting competition from the US and Europe

China's electricity supply and demand are going to change in different ways in the next three decades compared with the last three decades, the salient aspects of which will be dissected in the following sections.

Electricity supply

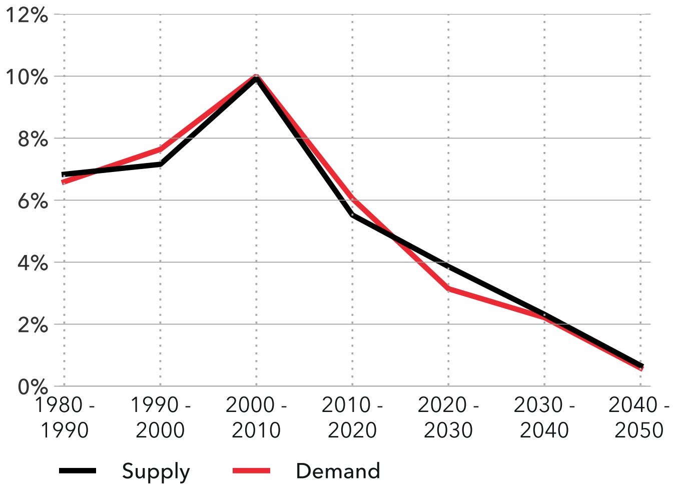
We forecast China's grid-connected electricity generation to grow from 9.2 TWh/yr in 2022 to 16.5 TWh/yr by mid-century. As impressive as these numbers are, they indicate a marked slow-down in electrification (see Figure 4.2). By contrast, the period from 2000 to 2019 saw a massive increase in electricity demand which led to the rapid expansion of the coal power fleet in China to the point where half of the world's total coal power capacity and half of global annual coal electricity is now in China (DNV, 2023a).

Given the lack of other fossil fuels, coal was China's go-to source for cheap growth in electricity supply, but it was not the only source of new electricity for China. China also kick-started the industrial-scale manufacturing of clean energy technologies, from solar panels and wind blades to power converters. This was aided in part by aggressive policies to incentivize such production, but more so to neutralize the market-based industries of other regions, most notably Europe (CREA, 2023).

FIGURE 4.2

Annual average growth rates of electricity supply and demand by decade

Units: Percentages/yr



This ensured that record levels of renewable power plants also came online in China, especially from the 2010s. In fact, variable renewable energy sources (VRES) such as solar and wind have overtaken coal and gas-fired power plant installations since 2019. Besides kick-starting the clean energy industries, curbing excessive local air pollution caused by coal-fired power plants was a major motivation for installing VRES plants.

Going forward, China's electricity generation sector (Figure 4.3) will be occupied with continuing to grow VRES while ensuring resource adequacy and flexibility. Until 2030, coal will continue to play an important role in the electricity supply, accounting for almost 50% of on-grid electricity generation despite its share reducing gradually from 2023. From 2030, the following two decades will see a very fast transition/substitution happening: the share of coal will dwindle, while wind and solar make up for the lost coal generation.

Central to maintaining adequacy and flexibility while increasing the share of VRES is electricity storage, the share of which in the on-grid supply in energy terms (TWh) will increase from near-zero in 2022 to about 4% in 2050 (see detailed analysis in Section 4.3, Storage and flexibility).

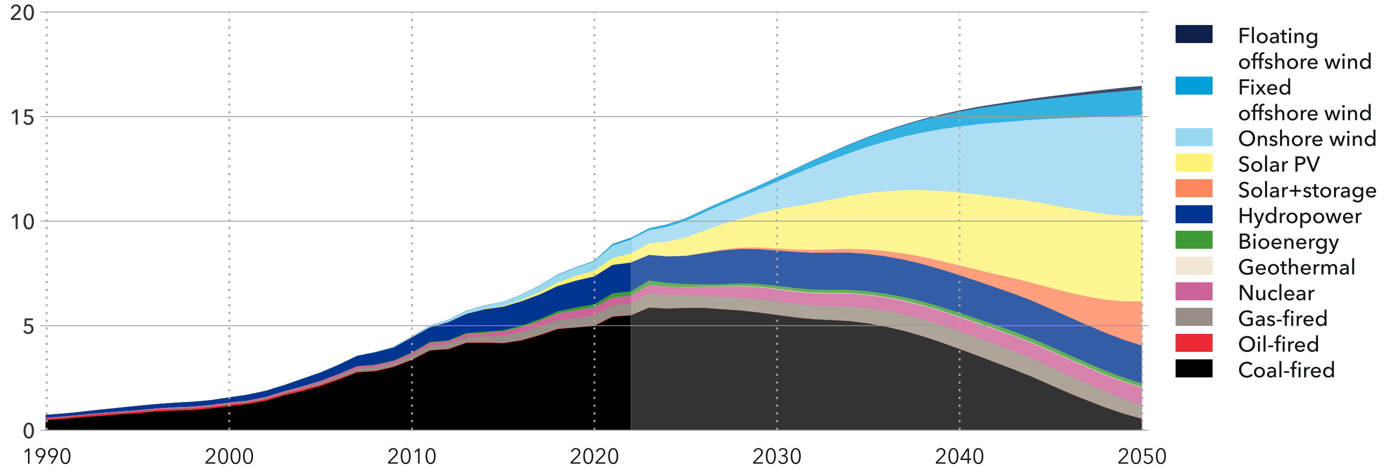
Given this transition to VRES and low-carbon power sources, the next three decades of China's grid-connected electricity generation (Figure 4.3) can be delineated into three time-phases, with changing priorities and accompanying policies all shaping the transition. The time-phases, the priorities for each of them, and the policies which aim to support the priorities are given in Table 4.1 overleaf.

> Until 2030, coal will continue to play an important role in the electricity supply, accounting for almost 50% of on-grid electricity generation.

FIGURE 4.3

On-grid electricity generation by power station type

Units: PWh/yr



Historical data source: IEA (2023), GlobalData (2023)

TABLE 4.1

Priorities and accompanying policies for China's electricity supply

Time period	Priorities	Policies
2022-2032	Maintaining adequate firm and ramp-able capacity, while continuing to phase in VRES	Capacity mechanisms for coal-fired capacity, ensuring coal capacity is profitable even while not generating electricity and is on stand-by during winter and summer demand peaks (Haley & Howe, 2023)
		Market-based economic incentives for renewable electricity beyond Central and Provincial-level subsidies, such as electricity trading spot-markets at a central level (NDRC, 2023c; RMI, 2023) Central support for strategic battery market to grow electricity storage (Xu, 2021), or 'pairing policy'
	Laying the foundation for long-term energy security	Ensuring there is no significant growth in gas-fired power plants by 'de-prioritizing' them through disincentives, since China is dependent on imported natural gas (DNV, 2023a) Dedicating funding to the development of nuclear power for firm capacity needs (DNV, 2023a; Murtaugh, 2023)
	Work-around for electricity and demand geographies	Plan and begin the re/location of major demand-centres from existing rust-belt to 'sun and wind' locations (You, 2022) Funding the expansion of an ultra-high-voltage power grid to ensure adequate interconnection of the provinces, which enables a robust power system (Zhang et al., 2023)
2032-2042	Consolidating energy security	Continuing the uptake of VRES through efficient spot-markets while phasing down and retiring gas-fired power plants (NDRC, 2023c) Despite the more likely non-favourable economics, ensuring the installation of nuclear capacity through 'premiums' and funding technological advancement of smaller units and small modular reactor technologies
	Striving for carbon neutrality in the power sector	Phasing down coal-fired generation while maintaining stand-by capacity for peak demands through capacity mechanisms (Hove, 2023) Ensuring the smooth operation of VRES through economic incentives such as power-price arbitrage for storage and a functioning electricity spot-market
2042-2050	Achieving as much decarbonization as possible	Scale-up of CCS for coal-fired power plants through support for CCS and efficient carbon trading markets (Communication with experts, 2023) Expansion of the nuclear fleet through continued support mechanisms such as 'premiums'
	A fully functional VRES-integrated electricity system built on dispatchable storage	Policies favouring the co-location of storage with solar to ensure dispatchable renewable electricity Technological development to enable majority two-way charging and to integrate vehicle-to-grid storage capacity into the power grid

As suggested in Table 4.1, nuclear power will play a fairly prominent role in the power mix with its share in grid-connected generation increasing from 4% in 2022 to about 5% by mid-century, a 550 TWh increase in the corresponding time. By mid-century, solar and wind combined will share about three-quarters of the total generation, while coal will have a paltry share of 3%. 93% of the total on-grid electricity generation will come from low-carbon energy sources in 2050 (Figure 4.3).

Power capacity

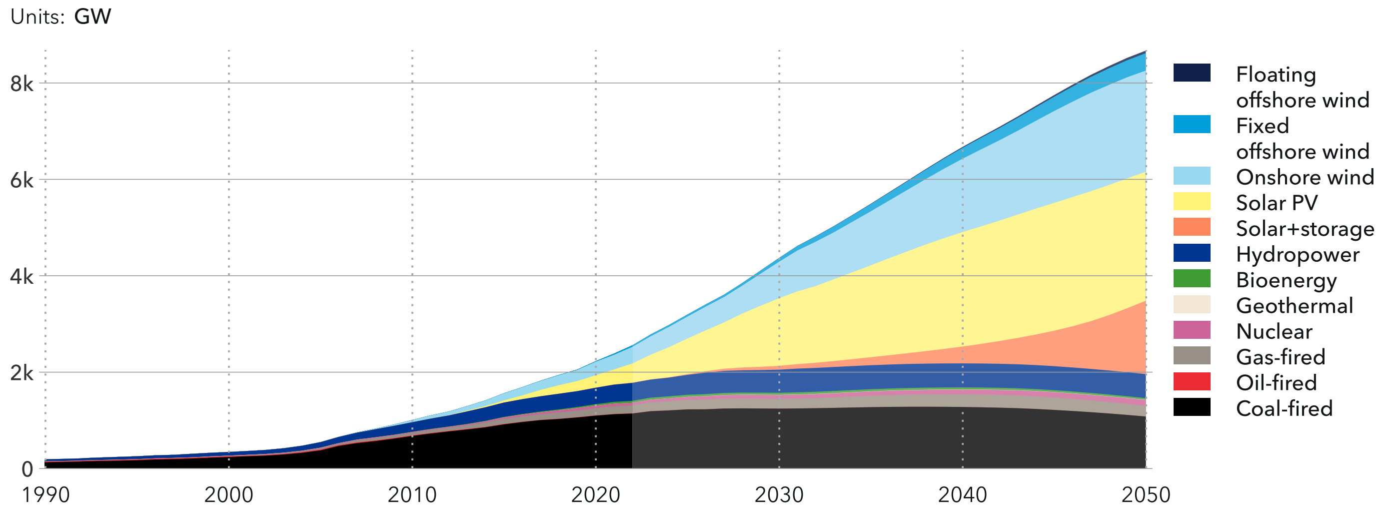
China's grid-connected installed capacity grows from 2.6 TW in 2022 to 6.7 TW by 2040, and reaches 8.7 TW by 2050. Unsurprisingly, both solar and wind dominate power capacity in China, their combined share growing from 30% in 2022 (780 GW), to 50% by 2030 (2.3 TW), and to 77% (6.7 TW) by 2050 (Figure 4.4).

One defining feature of China's electricity supply is the maintenance of coal capacity, through established capacity payment mechanisms, even while generation is declining. If one looks at the installed grid-connected capacity of China shown in Figure 4.4, coal-fired capacity accounts for about 13% of total capacity in 2050, while it accounts for only 3% of the total generation (Figure 4.3).

The installed grid capacity is a function of capacity additions and retirements in China's power plant fleet. Figure 4.5 shows the net capacity additions for selected types of power plants as yearly averages by decade. While the decade preceding 2020 saw high net installations of coal power plants, in the future, net coal power plant

FIGURE 4.4

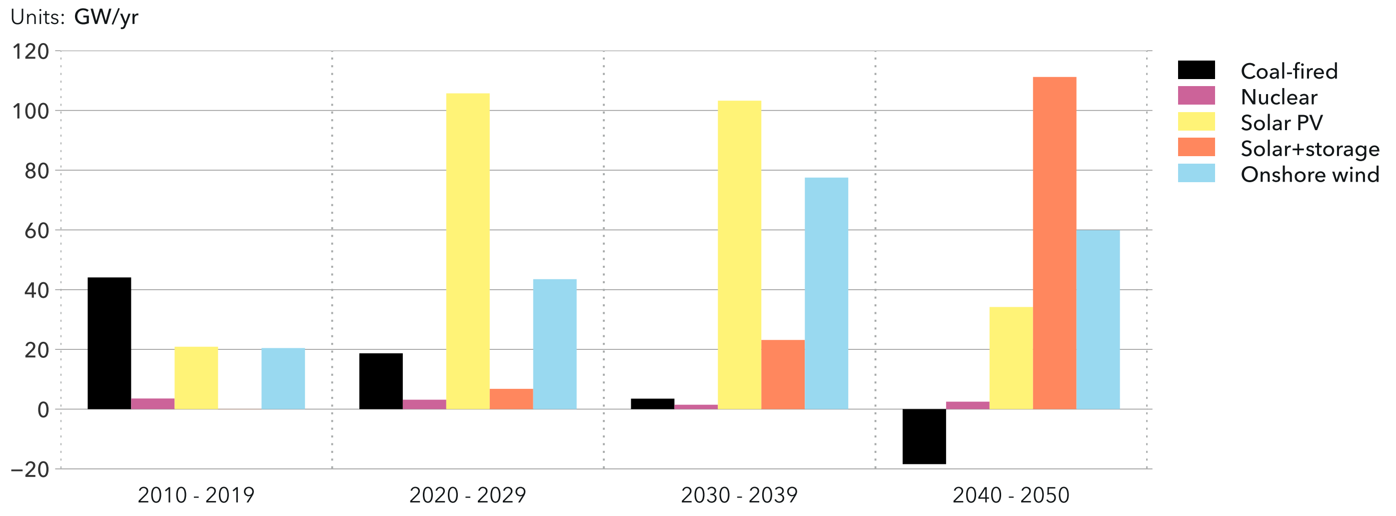
Grid-connected capacity by power plant type



Historical data source: IEA (2023), GlobalData (2023)

FIGURE 4.5

Annual average capacity additions by decade of selected power plants



capacity coming online is going to be lower than solar PV and wind capacity. Despite this, the capacity mechanism payment for coal leads to positive, albeit small, capacity additions, meaning that capacity coming online is still higher than capacity being retired.

As more and more solar PV comes into the power system, the price cannibalization effect becomes apparent, and the price solar electricity garners (which is termed as average received price) starts reducing. Over time, solar+storage becomes a profitable option for developers, which is also reflected in increasing net capacity additions of solar+storage, in absolute numbers and when compared to solar PV.

Figure 4.6 shows the spread of levelized cost of energy (LCOE) versus the average received price of electricity from selected power plants in China. While the LCOE of solar PV is lowest among all the featured types of power plants, the received prices of this solar PV electricity is also commensurately low. On the other hand, solar+storage, which is dispatchable and provides flexibility, has higher received prices, in general. Coal has increasing LCOE, due to increasing carbon prices but at the same time it also garners higher received prices during the limited hours that it does supply electricity to the grid.

Electricity demand

Although growing more slowly than in the 2000s, electricity demand in China will undergo a quiet revolution in three key aspects:

- Growth of new demand segments such as space cooling and other appliances and storage charging
- Intra-year/seasonal demand variability increases, with a more pronounced peak in summer, leading to peakier demand within a year
- In combination, higher growth in annual peak demand, despite slower in annual electricity demand growth

Figure 4.7 presents the evolution of electricity demand in China, from 2022 to 2050. Total annual electricity demand increases from about 9.6 TWh/yr in 2022 to about 17 TWh/yr in 2050, dominated by manufacturing and buildings electricity demand.

In 2022, manufacturing accounted for a little more than half of all electricity demand, with buildings accounting for a quarter and the rest spread equally among energy sector own use and others. This electricity demand structure is set to change by 2050, with manufacturing growth slowing down in China, even while electrification of manufacturing is seeing modest growth. Total manufacturing electricity demand remains almost constant from 2022 to 2050 (Figure 4.7).

By 2050, buildings electricity demand will be equal to manufacturing electricity demand, spurred on by a climate that is warming along with higher penetration of air-conditioners as more and more households in China can afford them.

This can be further explained if one were to break down the unique electricity segments within these demand categories (Figure 4.8). For manufacturing, base material electricity demand sees very small growth over the three decades, despite reducing total energy demand due to higher rates of electrification. On the other hand, electricity demand for manufacturing of all other goods reduces slightly, thus maintaining almost the same electricity demand in manufacturing.

The end-use with the highest electricity demand in buildings in 2022 is appliances and lighting, followed by heating uses (space, water, and cooking), then finally space cooling (Figure 4.8). However, with increasing global warming and rising prosperity, space cooling (specifically air-conditioners) energy demand will overtake the other two end-uses by 2030s, while electric heat demand in buildings will actually peak in 2040s and slightly reduce to 2050.

Most importantly, spurred on by EVs, transport electricity demand increases from 116 TWh/yr (1%) in 2022 to 1,142 TWh/yr (8%) by 2050, an average annual growth of 12%. Similarly, storage charging is another demand category which sees eight-fold growth from 2022 to 2050, reaching 800 TWh/yr in 2050.

FIGURE 4.6

Spread of levelized cost of electricity versus the average received price for selected types of power plants

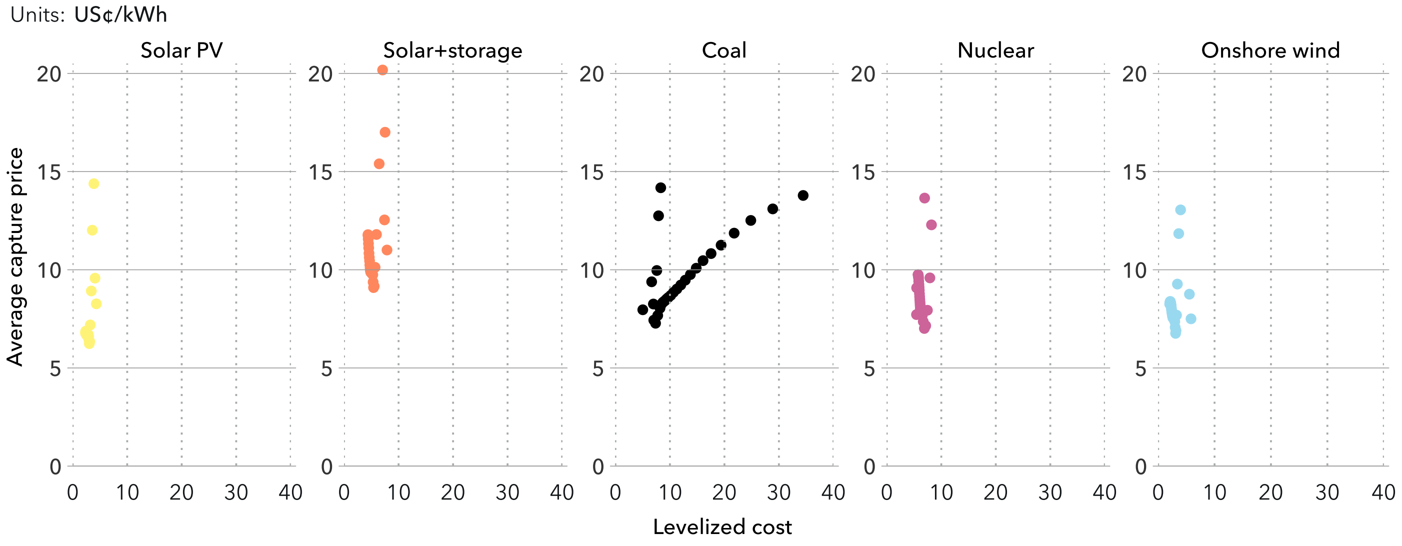


FIGURE 4.7

Electricity demand by segment

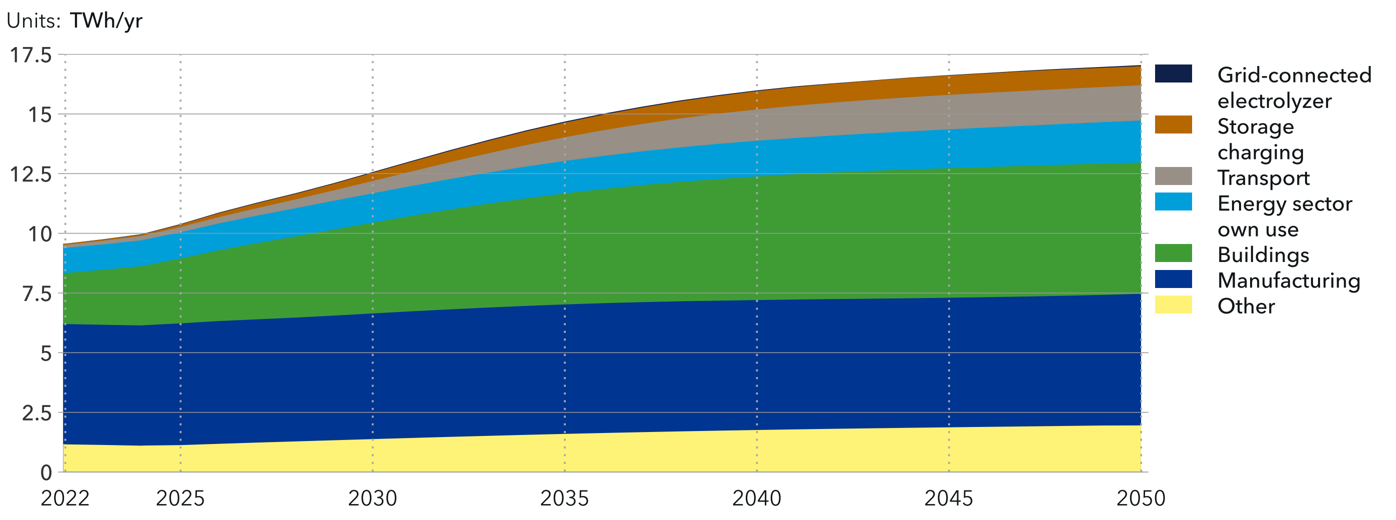
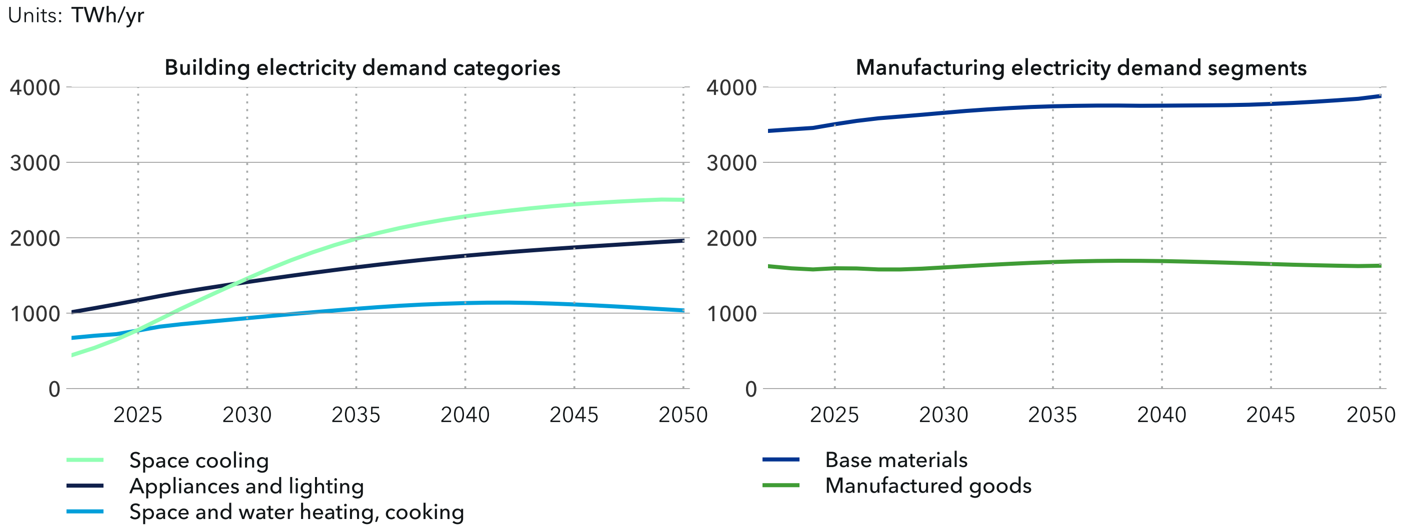


FIGURE 4.8

Breakdown of buildings and manufacturing electricity demand



4.2 Power grids

China’s grid capacity expands by 120% from 540 TW-km in 2022 to 1,200 TW-km by mid-century, owing to the vast amount of renewables coming online. Since the country is large, and different energy sources and demand-centres are concentrated in far-flung places, the power grid acts as a high-speed network that enables instantaneous electricity transfer, while making cleaner electricity more affordable over time.

Power grids are important for China to meet its economic, social, energy, and CO_2 emissions targets because grids are needed to:

- Transport electricity between the dispersed geographical locations of China's VRES and other energy sources and its large demand centres
- Achieve energy security and independence through clean electricity and to phase out fossil fuels
- Connect the different provinces and regions of China to increase efficiency and efficacy of access to electricity and electricity markets (IEA, 2023b)
- Enable shorter time-frame and spot-markets for electricity, especially renewable electricity, and in turn, faster de-regulation of the power sector (IEA, 2023b)

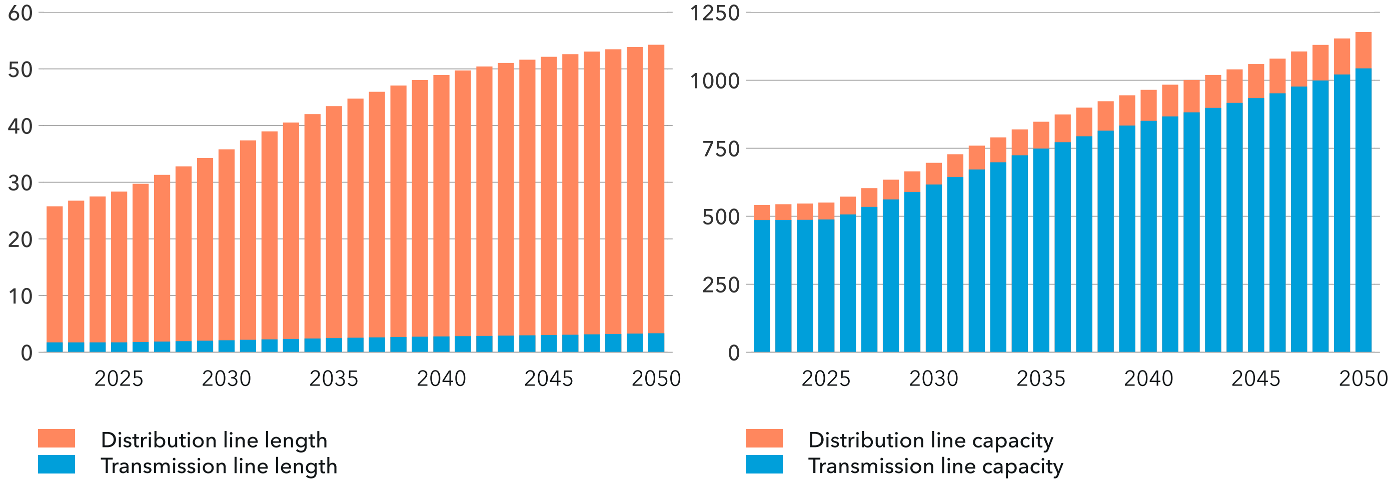
Figure 4.9 shows the forecast grid expansion in China, both in terms of grid length given in circuit-kilometres (c-km) and in grid capacity given in terawatt-km (TW-km). While total grid capacity grows about 3% year-on-year, grid length grows about 2.7% year-on-year from 2022 to 2050, signifying that transmission grid expands at a slightly faster pace than the distribution grid compared to the existing electricity access rates in China.

The power grid can be divided into two fundamental components: the transmission and distribution grid. The transmission grid transfers electricity over long distances at higher rated power, while the distribution grid distributes power to smaller consumers such as households and public or commercial consumers at a lower rated voltage and power.

FIGURE 4.9

Grid expansion by length and capacity

Units: Million c-km (left); TW-km (right)



Transmission grid

The transmission grid is made up of high-voltage (HV), extra-high-voltage (eHV), and ultra-high-voltage (UHV) lines (collectively referred to as HV); step-up and step-down transformers; and other accoutrements which connect utility-scale power plants and large-scale demand centres to the main grid and transmit electricity over long distances at high voltages to minimize energy loss.

For transmission of electricity, one can either use alternating current (AC) or direct current (DC). While generally HVAC is cheaper, given the distance, terrain, and possible losses, in specific cases, HVDC may be more cost-effective than HVAC.

Over the last 10 to 15 years, China has invested a lot of resources in developing its transmission grid through long-distance UHV transmission lines, especially HVDC lines. In 2023 alone, the State Grid Corporation of China invested a record USD 77bn in transmission infrastructure and energy storage systems, up by 4% from 2022 (Rogers, 2023). We estimate the transmission grid component of this investment level to double by 2032.

A major focus of spending has been on HVDC lines interconnecting the provincial and local grids, enabling the supply of electricity from remote (renewable) generation sources to load centres. Currently, China has the highest capacity of UHV lines of any single country. Furthermore, transmission lines are an essential part of the electric corridors planned in the *14th Five-year plan*, which aims to transmit significant renewable power capacity from the west of China to the east (Government of China, 2021).

Figure 4.10 shows the development of the transmission grid capacity, divided into HVDC and HVAC. At present, the HV lines are divided 80:20 in terms of AC to DC in grid capacity and this ratio is more or less preserved until mid-century. Total transmission grid capacity increases from 490 TW-km in 2022 to 1,050 TW-km by mid-century.

At present, the majority of the HVDC cables are overhead lines. We forecast this changing with the installation of offshore wind farms, in the future. By mid-century, a major portion of the HVDC lines are going to be undersea cables connecting offshore wind power plants off the East and South China Sea to the major coastal cities, which are also economic powerhouses of China. As shown in Figure 4.11, the length of undersea lines are going to expand starting from the 2030s as offshore wind power projects proliferate and shift further offshore where the economics of DC cables become even more favourable.

HVDC lines are especially suited to offshore applications and are cost-effective in more cases compared to HVAC lines, especially with longer distances from shore, which we expect in the longer timeframe. In the near future, low frequency AC cables are also looking promising in marine operations (China Daily, 2022).

China aims to become a world leader in both UHV transmission grid and HVDC technologies through its investments, which is also part of China's *Belt and Road Initiative* (Temple, 2019). Beyond this, Chinese state-owned enterprises and firms/organizations are involved in installing UHV lines in parts of the world where these lines will move renewable electricity from remote areas to its population centres, such as in the Amazonian Brazil (Leal, 2016). From being a necessity, HVDC lines are increasingly used as a strategic export by China, and its first mover advantage is expected to hold out long into the future.

Distribution grid

The distribution grid is made up of low-voltage (LV) and medium-voltage (MV) lines and step-down transformers. These get low-voltage power across to distributed consumers such as households, hospitals, and schools. The distribution grid is expected to grow from 24 million c-km in 2022 to 51 million c-km by mid-century, with its grid capacity growing from 56 TW-km to 134 TW-km during the same time-period.

Figure 4.12 shows the growth of LV and MV lines in China. Both LV and MV see similar growth, even though in 2022 China has near universal electricity access. The main reason for the growth in the distribution grid is the increasing electricity demand among the different domestic, commercial, and small industrial consumers. With increasing electricity demand, and electrification of key demand sectors such as passenger transport and building heating and cooling, it is vital that the distribution lines are strengthened to handle the demand so that critical services are not interrupted in the future.

One reason for the growth in LV distribution lines is that the electricity demand is becoming peakier with the penetration of air-conditioners and other high-powered appliances such as induction cookers and electric storage water heaters, along with EV charging growth in China. As prosperity grows, more people seek comfort and can afford space cooling and other appliances. Similarly, with increasing global warming and a higher incidence of extreme high temperatures in China, air-conditioners are also becoming a necessity. Thus, as the demand becomes more jagged/peaky, the distribution grid needs to be designed to handle demand loads even at the highest demand. Thus, LV lines are growing in both length and capacity.

Similarly, the growth of distributed solar, especially on rooftops, also requires both LV and MV grid strengthening, especially since many provincial grids are already at capacity in terms of integrating distributed solar.

> With increasing electricity demand, and electrification of key demand sectors such as passenger transport and buildings heating and cooling, strengthening the robustness of the electricity sector is key to uninterrupted critical services.

FIGURE 4.10

Transmission grid evolution

Units: TW-km

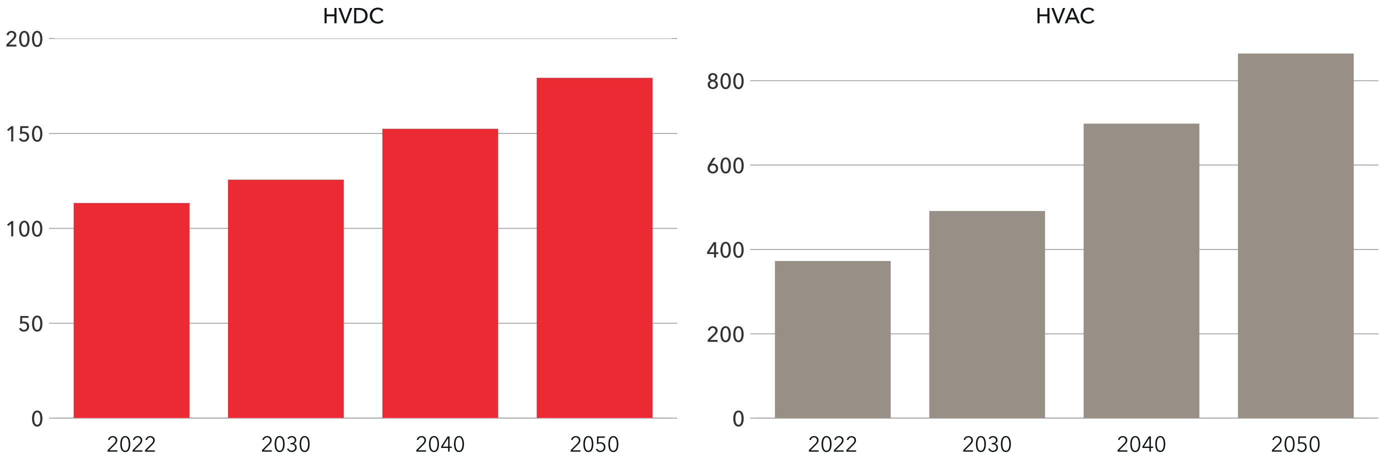


FIGURE 4.11

HVDC line development

Units: Thousand c-km

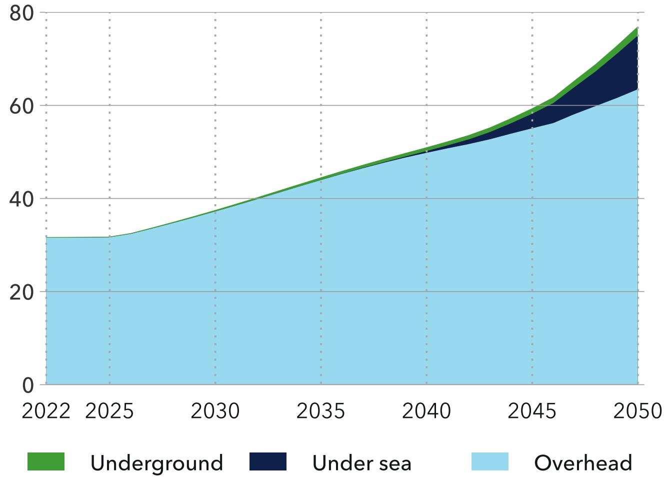
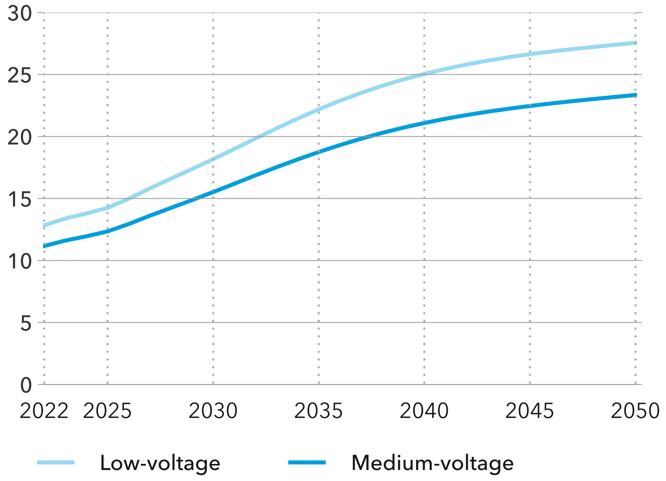


FIGURE 4.12

Low- and medium-voltage grid growth

Units: Million circuit-km



4.3 Storage and Flexibility

A strong government policy framework, investment in a range of technologies, and an emphasis on both domestic and international market competitiveness characterize China's approach to energy storage. The policies are not only focused on technological development, but also on integrating energy storage into broader energy and industrial strategies.

Policy landscape

China's energy storage and flexibility landscape is shaped by an array of ambitious policies and initiatives aimed at reshaping its power sector. At the heart of this transformative agenda is the *National Energy Storage Policy* which emphasizes the development of advanced storage technologies to enhance grid reliability and renewable integration. This aligns with the broader goals outlined in the nation's *Five-year plans* which consistently prioritize energy innovation and sustainability. A key component of this strategy is the *Made in China 2025* initiative, which seeks to domestically produce critical energy storage components, reducing reliance on foreign technology and promoting self-sufficiency. Additionally, various other programmes focus on incentivizing research, development, and the deployment of energy storage solutions across the country (see Table 2.3).

Flexibility needs

Figure 4.13 shows the changing requirements for flexibility in China's electricity supply leading up to 2050. We expect the need for flexibility to triple from now to mid-century. At present, the hourly demand fluctuates by about 200 GW from the daily average, representing 18% of that average. This variation results from the daily cycle of demand, with traditional power sources like coal, gas, and hydropower adjusting their output to meet these changes. The difference in electricity use between weekdays and weekends mainly causes day-to-day fluctuations, with the daily variation being roughly half of the within-day change. On an annual basis, the demand for electricity in China shows a slight seasonal pattern, balancing the needs for winter heating and summer cooling, with the highest demand in summer.

Over the next two decades, we anticipate a significant increase in flexibility requirements. This increase stems from a shift in electricity usage from industrial to more fluctuating residential needs, including heating, cooling, and EV charging. Such a change will not only increase short-term flexibility demands but also amplify seasonal requirements, particularly with an expected five-fold rise in cooling needs by 2040. Moreover, the variability in solar and wind power generation will further increase daily and weekly fluctuations. Specifically, solar power will contribute significantly to daily variability before 2030. Wind power, while also adding to the variability, has a less noticeable daily impact as it does not have the same daily patterns as solar power. Throughout the year, solar power shifts from creating variability to enhancing flexibility, aligning with the seasonal demand for cooling. On the other hand, wind power, which reaches its peak in winter, will become a key factor in seasonal variability. From 2040 to 2050, we expect the need for flexibility to keep growing, though at a reduced pace, as the balance between supply and demand in the electricity system stabilizes.

Flexibility providers

Traditional energy sources such as gas and coal will maintain their significance in China's energy portfolio through to 2040, although their expansion will not keep pace with the escalating demand for adaptable energy solutions. To bridge this gap, an array of storage options, including pumped hydro and batteries, will become more prominent. These systems, capable of operating both independently and in tandem with renewable energy, especially solar, are set to play a pivotal role. Electrolysers, harnessing surplus solar and wind power, are also poised to become integral to energy flexibility. However, their effectiveness is contingent upon the consistency of excess energy availability, as sporadic operation throughout the year is unviable.

Post-2040, with the gradual phase-out of coal power stations and the ascent of alternative energy sources, strategies such as curtailing surplus energy production will come into play. Curtailment will act as an emergency measure to balance the grid when the capacities of storage or electrolyser systems are fully utilized. The function of storage systems will evolve, transitioning from merely accumulating excess energy to releasing it during periods of reduced solar and wind energy output. This change is especially critical when conventional energy generation faces limitations. Furthermore, consumer involvement in demand response initiatives is expected to increasingly contribute to energy consumption management during peak times. After 2040, as coal power stations are retired, solar power combined with storage is projected to become the cornerstone of China's flexible energy approach, driven by the decreasing costs of batteries and solar technology.

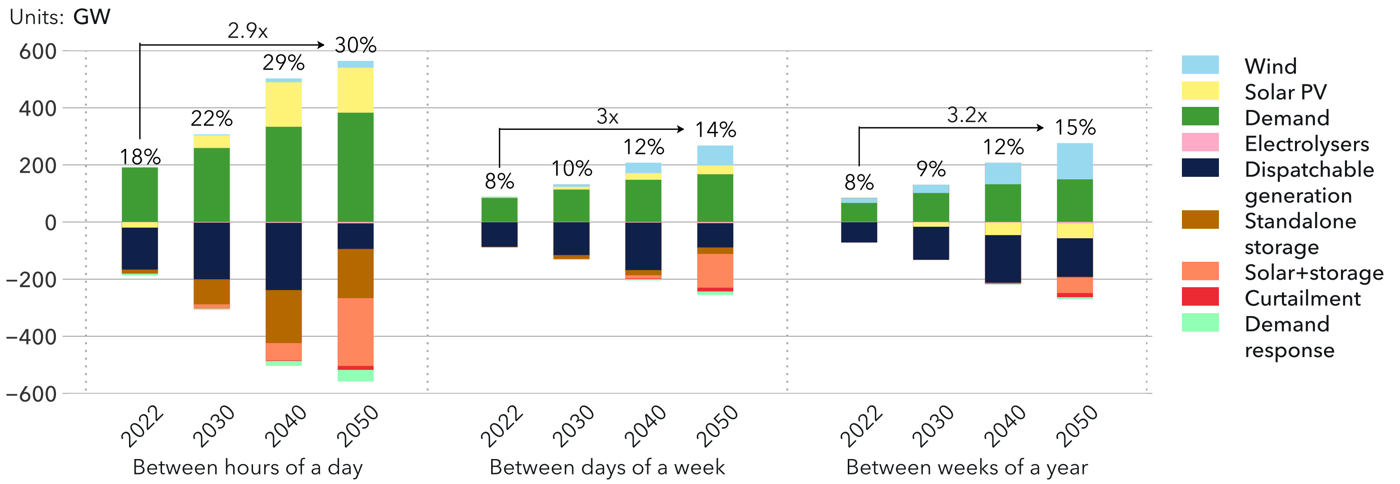
Interconnectivity within China's power grid emerges as another key facet. Government-led initiatives to enhance inter-provincial power trading (as detailed in Section 4.2) will significantly bolster grid flexibility. New regulations aiming to optimize resource allocation and energy efficiency will enable provinces with an abundance of renewable energy to supply those facing shortages, thus minimizing wastage and improving grid stability. This aspect is especially crucial considering the previously high rates of unutilized solar and wind energy in the northern regions, which have been a major impediment to the adoption of these renewable sources. Hence, these inter-provincial connections are essential for China's continued progression towards a decarbonized power system.

Simultaneously, China is reforming its approach to demand-side response (DSR). Moving beyond simply mandating industrial users cut back on consumption during peak demand, the focus is now on employing financial incentives to foster more flexible energy utilization. The influence of rural electrification is significant, extending the grid's reach and amplifying overall energy demand requires more sophisticated DSR strategies. Complementing this, smart city initiatives are propelling the advancement of more intelligent and responsive energy systems. The integration of technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI) is enhancing the efficiency of energy management, forecasting, and distribution, further fortifying China's DSR framework.

> The need for power system flexibility will triple from now to 2050 due to shifts in electricity usage from industrial to more fluctuating residential needs, including heating, cooling, and EV charging.

FIGURE 4.13

Flexibility requirements in the electricity supply by technology



Derived from hourly simulations without grid limitations, measuring variability through standard deviation changes attributable to each technology, where negative values indicate reduced variability and percentages represent standard deviation as a ratio to annual mean.

Market developments

Holding the position as the world's foremost nation in pumped hydropower, China boasts a capacity exceeding 50 GW, which accounts for nearly one-third of the global total. The country is actively developing more pumped hydro facilities, with a strategic plan to significantly boost its capacity. Predictions suggest that by the mid-2030s, this capacity could surpass 200 GW and 2 TWh, and potentially reach around 250 GW and 2.7 TWh by 2050 (Figure 4.14). Compared with other storage methods like batteries, pumped-storage systems offer notable benefits, including their longevity, low operational and maintenance expenses, and their ability to store energy on a large scale for extended periods. Despite these advantages, they are not without drawbacks. The initial investment for construction is substantial, and these projects can have environmental and ecological impacts. Additionally, their establishment is limited by geographical and water availability constraints.

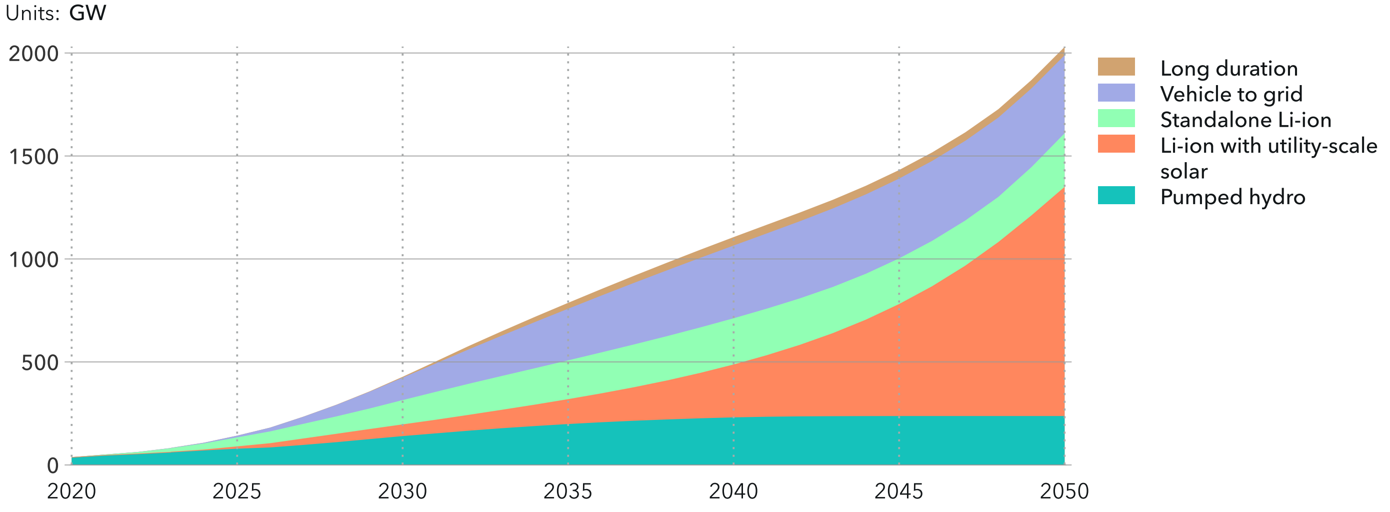
Due to decreasing costs, governmental financial incentives, lower electricity tariffs for storage operations, and a supportive policy environment, standalone utility-scale lithium-ion (Li-ion) batteries are poised for rapid expansion in the coming decade. It is anticipated that their capacity will reach 100 GW and 250 GWh before 2030, escalating to 220 GW and 675 GWh by 2040. Concurrently, the integration of solar power with storage will boost the growth of Li-ion batteries used in conjunction with solar systems. By 2050, this combination is expected to become the predominant form of utility-scale storage in China, exceeding a capacity of 1 TW and 3.7 TWh.

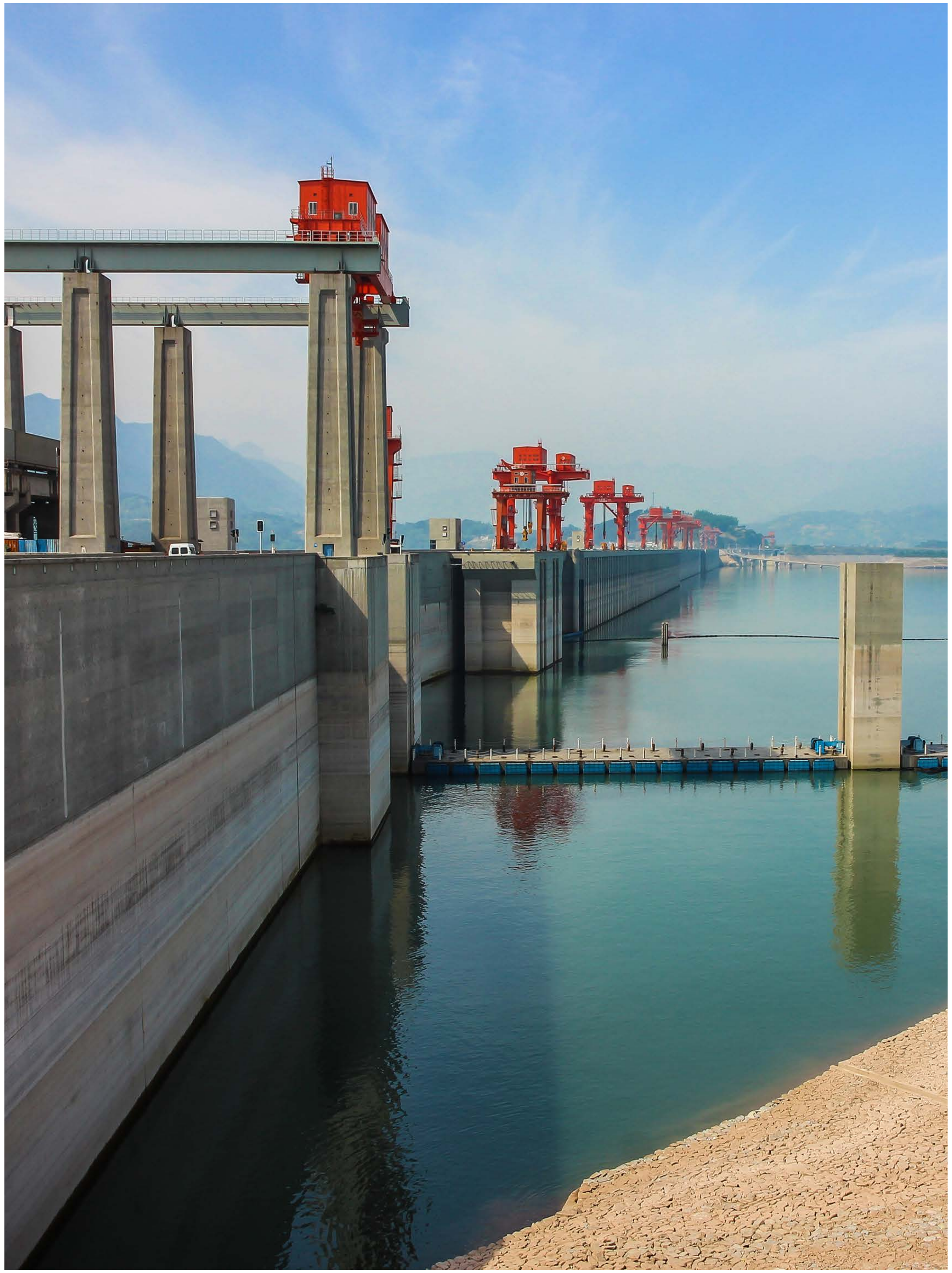
In response to the increasing demand for flexibility, there is a growing interest in alternative, long-duration storage technologies capable of storing energy for periods ranging from 5 to 24 hours. This category includes technologies like flow batteries, zinc-based batteries, and gravity-based storage systems. Projected to gain mainstream acceptance in the 2030s, these long-duration storage solutions are targeting a capacity of 40 GW and 345 GWh by 2040.

The swift uptake of EVs, combined with investments in smart grid technology and economic incentives from both China's government and local authorities, is setting the stage for vehicle-to-grid (V2G) systems to become a vital component in stabilizing the nation's power network. The National Development and Reform Commission (NDRC) of China has recently outlined a strategic plan for V2G integration (Industrial News, 2024). Key elements of this plan include the establishment of a comprehensive technical framework for V2G interactions by 2025, the full implementation of peak charging and time-based electricity pricing, and an emphasis on advancing core V2G technologies. Additionally, these guidelines aim to develop both national and industry-specific standards for V2G interactions, while also refining electricity pricing and market strategies to facilitate V2G integration. As the demand for grid flexibility grows, it is anticipated that financial drivers will increasingly support the expansion of V2G systems throughout China. We forecast that by 2050, V2G systems will contribute an additional 380 GW of storage capacity.

FIGURE 4.14

Utility scale storage power capacity





Balancing power supply and demand

China is transitioning to a VRES-dominated power system over the next three decades. We explain this transformation using the year 2050, and a typical summer and winter week as an example.

2050 hourly power supply and demand

China's power system will have a peakier demand in the summer months than in winter due to space cooling and appliances demand. Thus, there will be installed capacity throughout the year to sustain the summer demand. Coal power, along with both stand-alone solar and solar with storage, will supply more electricity in the peak period, while the wind power output is cumulatively less. Coal power output during the rest of the year is lower, which leads to an overall low annual capacity factor for coal.

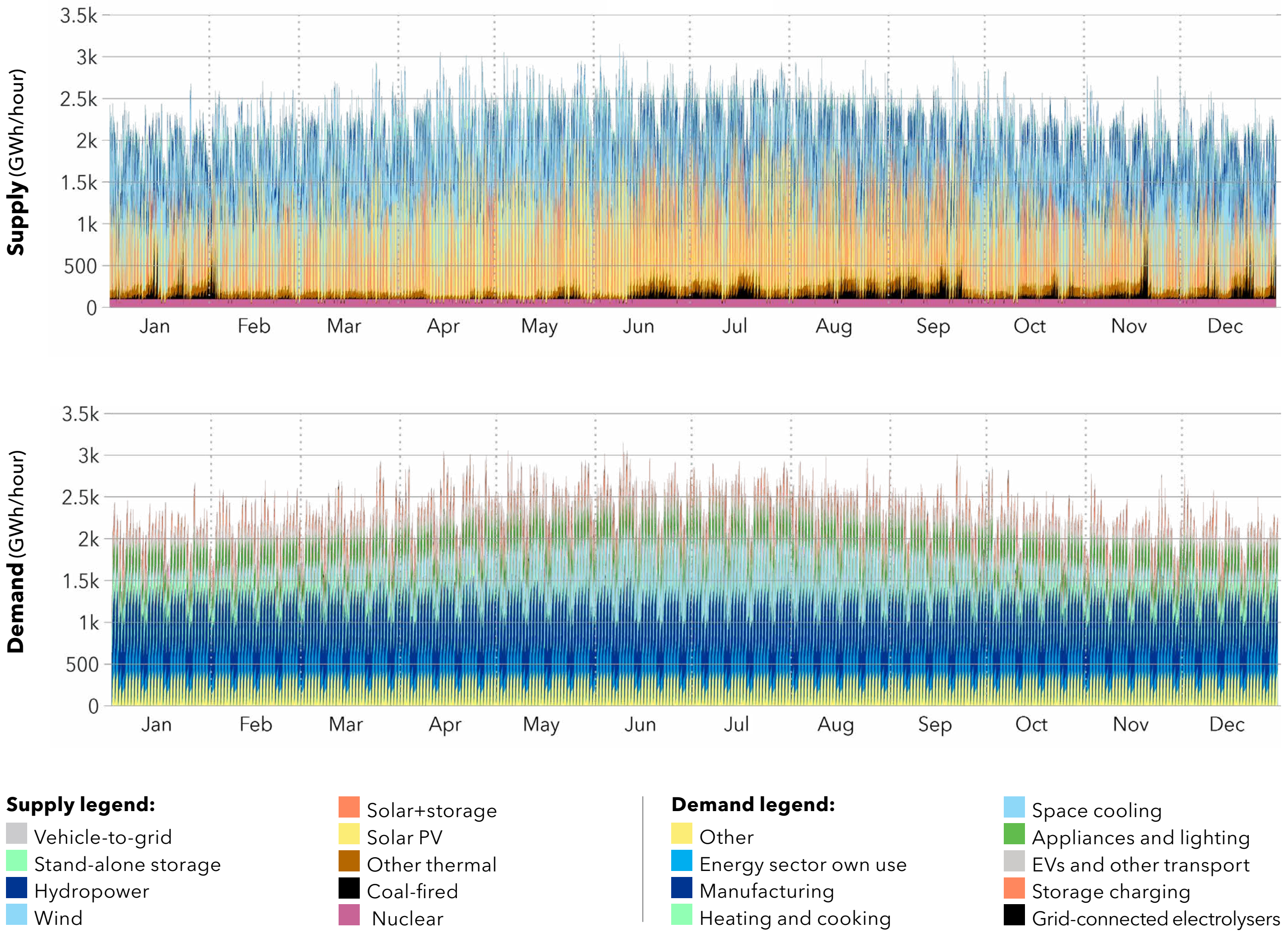
2050 Summer week

In summer the majority of baseload is provided by nuclear, while coal power fluctuates for daytime cooling peaks. With depressed output of wind due to seasonal low availability, solar PV with and without storage provides the bulk of the non-night-time demand in the week. The storages are charged during hours when VRES are cheap and plentiful, and then are discharged during hours of reduced solar generation, such as after dusk.

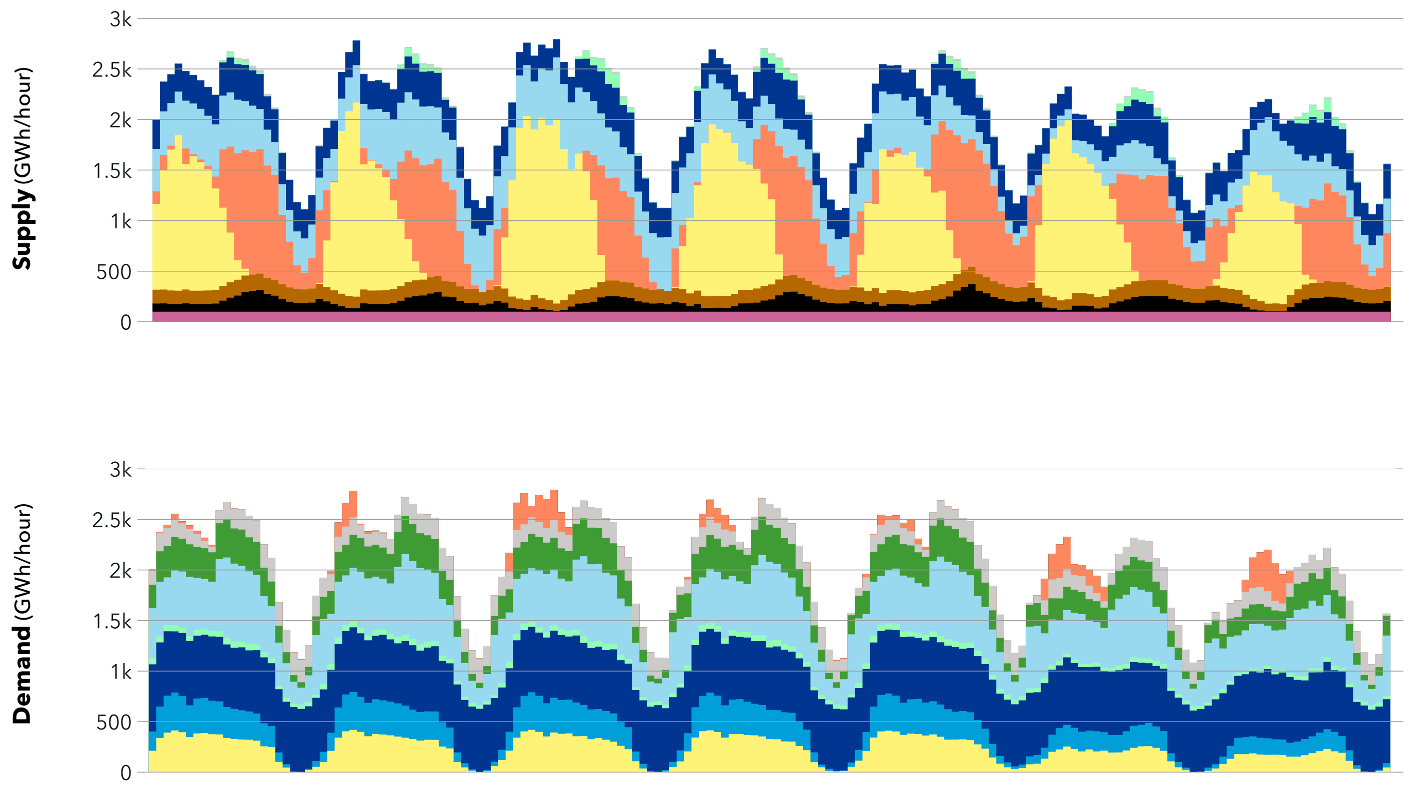
2050 Winter week

Coal generation only kicks in on some days when wind resources are low. Generally, wind generation is plentiful in China and complements solar PV during winter. Put together, during a typical winter day in China, electricity from wind and solar can satisfy about 80% of the demand.

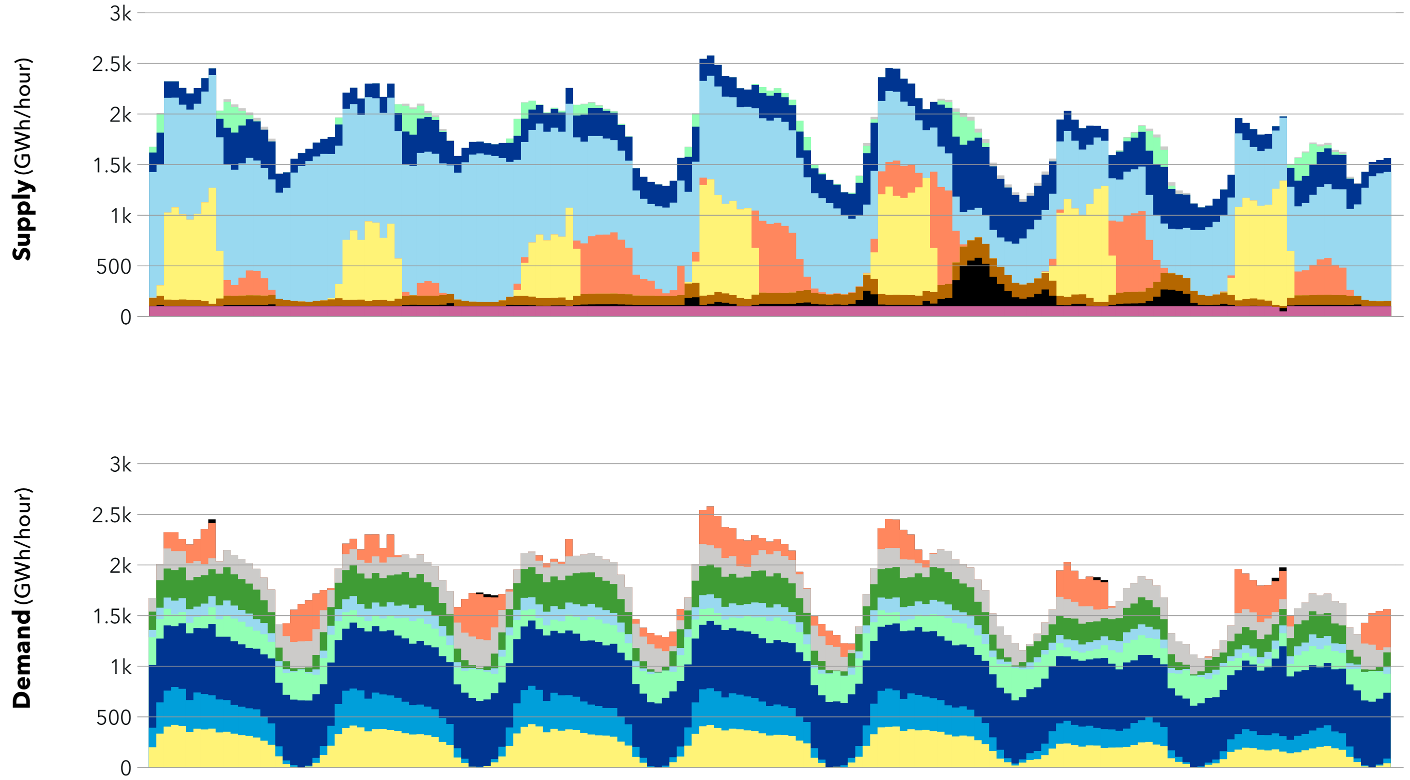
Hourly profiles in 2050



Summer week



Winter week



4.4 Hydrogen

China, the world's largest hydrogen producer and consumer, predominantly generates hydrogen through fossil value chains. In 2022, out of the close to 40 million tonnes produced, 80% came from fossil fuels, 18.5% from industrial by-products, and only 1.5% from electrolysis, with less than 0.1% using renewable energy. Because it is costly and available in very limited quantities, low-carbon hydrogen is confined to a small fraction of the transport sector so far.

With China's goal to achieve carbon emissions peak before 2030, green hydrogen is poised to play a crucial role in the nation's journey towards carbon neutrality. However, by the end of 2023, China's electrolyser capacity reached 1.2 GW, constituting half of the global capacity, with the addition of a new record-breaking electrolysis project at 260 MW already operational this year. Beyond its borders, China is solidifying its dominance in electrolyser deployment, with over 40% of global electrolysis projects reaching the final investment decision (FID) originating from the country.

The main challenges for an increasing production of low-carbon hydrogen and its by-products include:

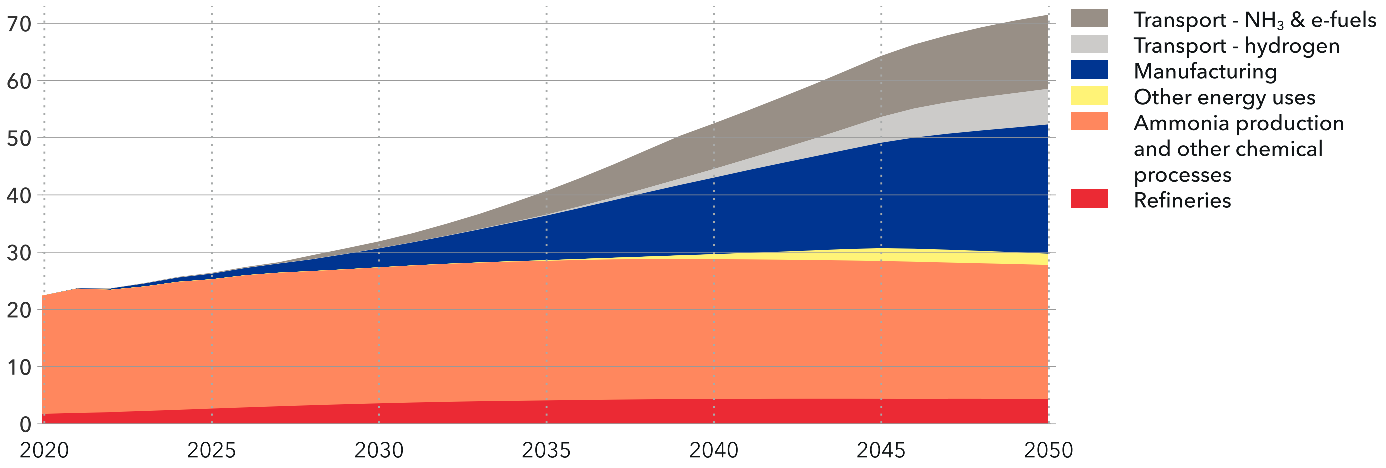
- High CAPEX, with electrolysis equipment being a major cost component
- Reduced capacity factors due to the intermittent nature of renewable power, leading to increased hydrogen production costs
- Limited access to financial support, which tends to favour established players with a proven track record over new entrants

Policy incentives for clean hydrogen
In March 2022, China's National Development and Reform Commission (NDRC) and the National Energy Administration collaborated to release the *Medium- and Long-Term Plan for the Development of the Hydrogen Energy Industry* (2021-2035). This marked the formal integration of hydrogen development into China's national development strategy and signaled a new era of growth for the country's hydrogen sector.

FIGURE 4.15

Hydrogen demand

Units: MtH_2/yr



Other energy uses includes electricity generation and buildings.

The plan establishes the criteria for the development of green hydrogen regarding the specified target timelines, outlining the necessary milestones and activities, such as:

- A *medium- and long-term plan for the development of the hydrogen energy industry (2021-2035)* with the key development goal of having about 50,000 fuel cell vehicles as part of the fleet and several hydrogen refuelling stations deployed (over 400). At the same time, hydrogen production from renewable energy is planned to reach 100,000-200,000 tonnes/year while achieving a carbon dioxide emission reduction of 1-2 million tonnes/year.
- There are 10 hydrogen-related policies at the national level, 83 at the provincial level, and 252 at the city/county level. Of these, development planning accounts for 45%, financial support 20%, project support 17%, management methods 16%, and hydrogen energy safety and standards account for 2%.
- Dozens of provinces/cities have implemented supporting schemes that cover both capex and opex support. Examples include CNY 3-10m for the building of hydrogen refuelling station, CNY 2m or CNY 6-35/kg for hydrogen station operation, and CNY 1.5-5m for the hydrogen transportation project (WEF, 2023).

Hydrogen demand
In 2022, the demand for hydrogen in China amounted to 25 million tonnes (Mt). Most of this demand (90%) was for the production of hydrogen derivatives methanol and ammonia, for example for fertilizers in the case of ammonia. The remaining 10% was for use in refineries for the enhancement of oil products. In contrast to these applications focused on feedstock, the demand for hydrogen as an energy carrier was infinitesimal in 2022.

Given the policy support for offtake outlined above, significant changes are expected. The demand for hydrogen as a feedstock is projected to grow by 20% by 2050. By the 2040s, the demand for hydrogen as an energy carrier is forecast to surpass hydrogen feedstock demand, as depicted in Figure 4.15.

Our forecast indicates that hydrogen demand will reach 72 Mt by mid-century, for both feedstock and energy purposes. In this context, 'feedstock' encompasses the demand for hydrogen to produce ammonia and other chemicals like methanol, while 'energy source' includes hydrogen demand for direct usage in energy sectors or for the production of e-fuels and ammonia as a fuel.

Hydrogen demand as energy carrier in more detail
The demand for hydrogen for energy purposes is poised for significant growth, transitioning from nearly nonexistent levels at present to an estimated 43 Mt per year by 2050. About a third of this projected production will be allocated to the generation of derivatives, including

ammonia and e-fuels, catering to the maritime and aviation sectors.

The initial significant uptake is anticipated for industrial heat and the alternative fuel sector. This initial usage is strictly policy-based. Close to 5 Mt of hydrogen as an energy carrier will be used for the provision of industrial heat in just ten years, while by then about 3 Mt will be used to provide alternative fuels based on hydrogen. Subsequently, the direct utilization of hydrogen is anticipated to gain traction in long-distance trucking and aviation, with the transition occurring progressively from the late 2030s to the 2040s. About 0.3 Mt will be used in China's road sector in ten years.

Figure 4.16 illustrates in more detail the uptake of pure hydrogen and hydrogen derivatives. Pure hydrogen will mainly be used in long-distance trucking and in aviation in hybrid setups. Hydrogen derivatives will make bigger inroads into aviation and maritime. Hydrogen-based SAFs will add to a more diversified fuel mix in aviation, together with sustainable biofuels. Maritime will see a diversified fuel mix as well, and here methanol is currently the sustainable fuel getting the most attention, while we expect a higher share of ammonia in the long run. However, there are large uncertainties associated with that prediction which are further elaborated in our *2022 Maritime Forecast* (DNV, 2022).

It is important to highlight that the initial and ongoing uptake in the transport sector will primarily involve hydrogen derivatives such as ammonia and e-fuels or sustainable aviation fuels, rather than pure hydrogen.

Hydrogen supply

In the year 2022, the predominant method for producing hydrogen for energy was electrolysis, however this was at very low levels. Towards mid-century, hydrogen production via electrolysis will undergo tremendous growth in China (Figure 4.17). Primarily coupled with solar PV and to a lesser extent with onshore wind, electrolysis-based hydrogen production aiming at supplying hydrogen for energy will be at 30 Mt in 2050. Low-carbon hydrogen also makes inroads in hydrogen use for feedstock. By 2050, 80% of both hydrogen for feedstock and hydrogen for energy will be based on low-carbon hydrogen. The remaining 20% is split equally between methane reforming and coal gasification, both without CCS. Dedicated solar PV accounts for almost half of the low-carbon hydrogen production in China by mid-century, equaling 32 Mt. Electrolysis coupled with wind power production will account for about 15%, while electrolysis coupled with grid electricity will account for 10%.

The selection of the production route in this forecast is predominantly influenced by the levelized cost of the production routes.

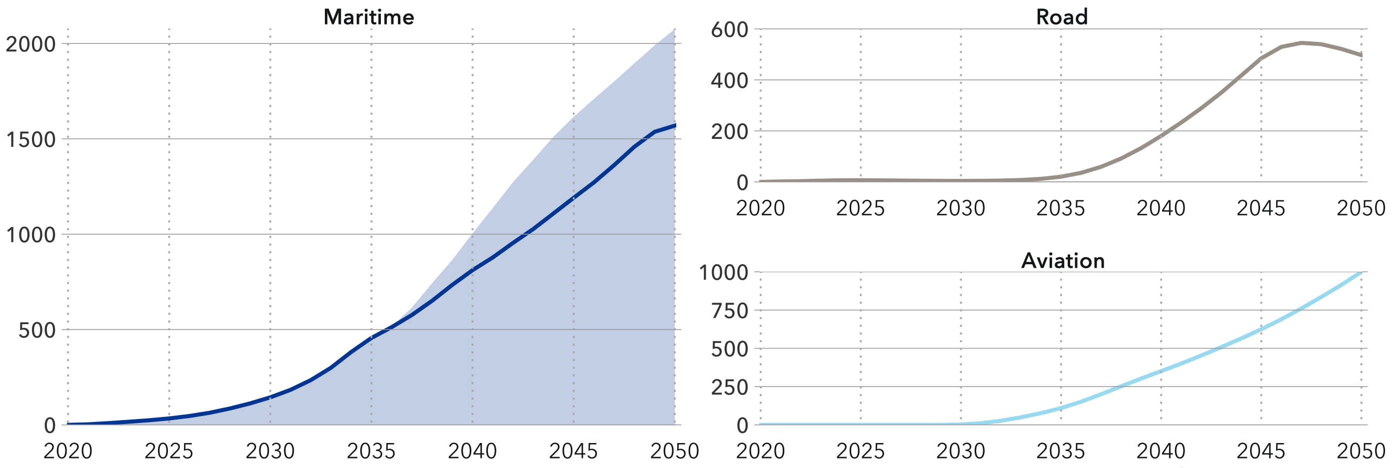
Prospects for green ammonia

In 2022, China had an annual ammonia production capacity of 55 million tonnes, constituting approximately 30% of the world's total capacity. This significant share primarily stems from the reliance on coal-based ammonia production, driven by the absence of larger natural gas reserves in China. Coal-based ammonia production is considered to be one of the most polluting methods, contributing to Scope 1 emissions of at least 4 tonnes of carbon dioxide per tonne of ammonia.

FIGURE 4.16

Hydrogen and derivatives demand in selected subsectors

Units: PJ/yr



Conversion factor: 1000 PJ = 1 EJ

Shaded area represents range of expected uptake as outlined in DNV's Maritime Forecast to 2050

Coal-based ammonia production is typically more costly than natural gas-based production, particularly in countries with low-cost natural gas. Due to limited natural gas reserves and thus lower capacity, but also political will for CCS, decarbonization in China must likely occur through either exporting carbon dioxide via pipeline and ship or, more feasibly, through electrolysis-based pathways combined with renewables. China already boasts gigawatt-scale factories for electrolyser production at a significantly lower cost than Western manufacturers.

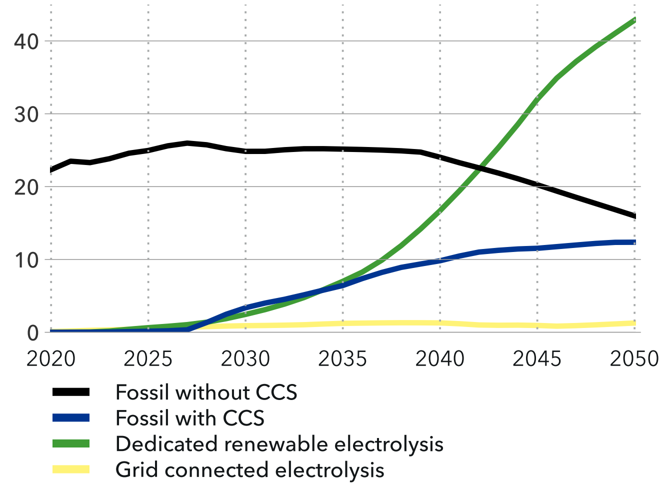
> The cost gap between fossil-based and electrolysis-based ammonia production in China is arguably the world`s smallest.

China recently revealed plans for numerous large-scale renewable green ammonia plants utilizing its enormous land mass and the ability to develop large-scale projects quickly. While demand for ammonia for feedstock reduces slightly by 2050, down to 51 Mt, the demand for ammonia as an energy carrier rises from virtually zero today to 57 Mt. Coincidentally, 2050 also marks the first year in which ammonia demand as an energy carrier is bigger than ammonia demand for feedstock in China. About a third of the low-carbon ammonia production will come from renewables, either via the grid or dedicated renewable production, the rest will come from fossil sources equipped with CCS. However, domestic ammonia production will only cover about a tenth of China's demand. Thus, a large proportion of the ammonia demand, about 40 Mt, will be imported from North East Eurasia in the form of blue ammonia.

FIGURE 4.17

Hydrogen supply by production route

Units: MtH_2/yr



Prospects for green methanol

At present, methanol is primarily utilized for chemical production, specifically in the production of formaldehyde, and is infrequently used as a fuel. Nevertheless, a growing initiative to promote methanol-powered transport in China may alter its prospects.

The merits of utilizing methanol as a transportation fuel are manifold. It boasts lower production costs in comparison to alternative fuels and is less flammable , ensuring enhanced safety in engine usage compared with gasoline. Moreover, its liquid state at ambient temperatures facilitates convenient storage and distribution. Furthermore, when produced from renewable sources and biomass or through carbon capture methods, methanol is regarded as a low-carbon fuel.

As outlined in the Chapter 3.1, Transport, the maritime industry is currently experiencing a transition in fuel technology, with 50% of the newly ordered tonnage being equipped to utilize LNG, LPG, or methanol in dual-fuel engines. This is a marked increase compared to the one-third of tonnage on order in the previous year.

In November 2023, shipping giant AP Moller-Maersk announced the conclusion of a long-term agreement for an annual off-take of 500 kt of methanol (a mix of green bio-methanol and e-methanol) to be delivered by Chinese new energy pioneer, Goldwind. This production is intended to meet a large proportion of the fuel needs of Maersk's 12 large container vessels under construction, equipped to utilize methanol, with the initial volumes anticipated to be delivered in 2026. Production is scheduled to commence in 2026 at a new facility located at Hinggan League, northeast China.

We forecast a production of methanol intended for energy use, such as transport fuel, to reach 5.5 Mt by 2030, and close to 60 Mt by 2050 stemming mainly from non-fossil sources. Only 10% will be produced via CCS-equipped fossil value chains.

5 ENERGY SUPPLY

In 2022, China accounted for 18% of the world's population and 20% of global GDP. Energy demand in China, hitherto closely correlated with both population and economic growth, has soared – growing from 12% of global primary energy in the year 2000, edging past 21% in 2010, and now accounts for 26% of global primary energy demand. Importantly, China is responsible for a third of global energy-related CO_2 emissions; developments there are crucial to whether the world will meet its emissions reduction targets and climate objectives.

China's primary energy supply has nearly tripled over the last two decades, as illustrated in Figure 5.1. The strong increase came first and foremost from coal, which accounted for 58% of primary energy use in China and 54% of global coal consumption in 2022. Since 2013, China's energy use has also started to diversify into almost all other energy sources, with strong growth in natural gas, hydropower, nuclear, solar PV, and wind. In 2022, China's renewable energy investments accounted for 55% of the global total (BNEF, 2023). Just two Chinese companies have captured over half of the world's electric vehicle battery market and 60% of electric car sales in 2022 occurred in China. It also has the world's largest fleets of solar and wind power plants. The most striking growth has been in solar power, where new installations in 2023 alone are expected to provide one-and-a-half times the total installed capacity of solar power in the United States (SEIA, 2023).

However, this remarkable progress in renewable sources has yet to crowd fossil sources out of the energy mix in China: the share of coal and oil will increase slightly in the next couple of years before they gradually decline to a fourth and a half, respectively, of their current volumes by 2050. In 2050, the share of fossil fuel in primary energy supply will reduce from 87% to 40%.

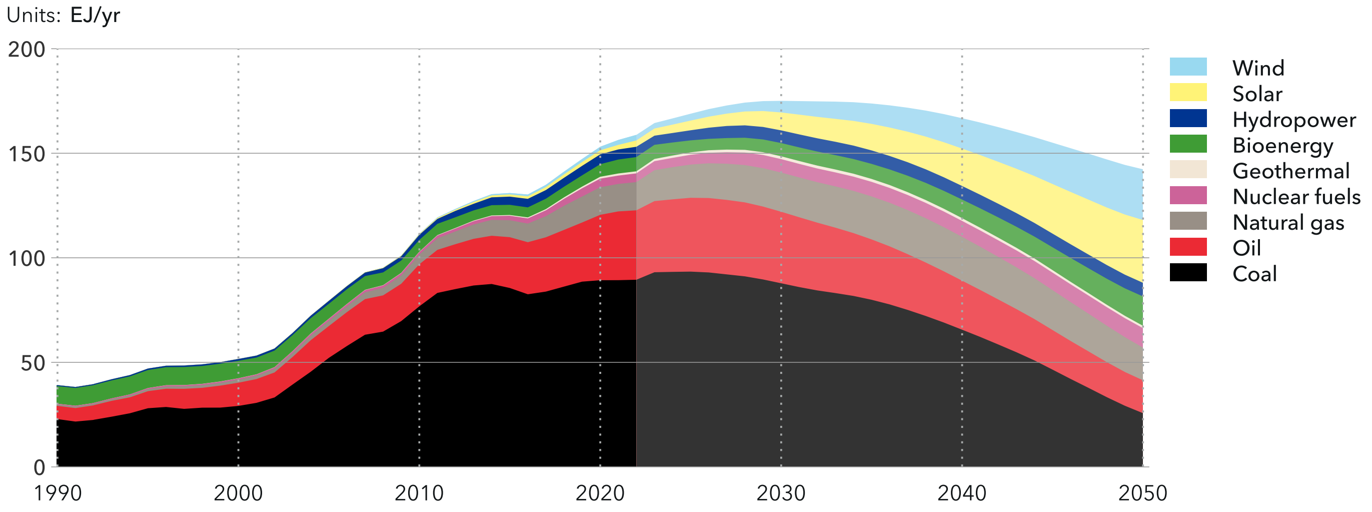
The forecast energy supply and demand trends in the coming decades are closely linked to the demographic and economic developments of the region. They are also strongly influenced by government energy and environmental policy. China's population peaked at 1.426 billion in 2022 (UNDESA, 2023), and is expected to be about 90 million less in 2050 than today. With an ageing population, the reduction in the workforce is even greater, and this influences productivity and economic growth. A smaller workforce means salaries are likely to grow more than in neighbouring countries. Even with increased automation, a significant share of China's manufacturing is likely to move to countries with cheaper production.

Average annual economic growth has been more than 8% for 30 years while the GDP per capita experienced a 10-fold increase in the same period. We expect growth to slow significantly to an average of 2.3% for the next 30 years due to the demographic shift described above, and because China is becoming a more mature economy with fewer productivity gains in industry and structural difficulties in sustaining domestic demand growth. Over time, its long-term economic growth rate will more closely resemble that of other middle- and high-income countries. However, slowing growth does not mean no growth: by 2050, GDP per capita is projected to be more than double its current value, reaching USD 50,000 per year.

> In 2050, the share of fossil fuel in primary energy supply will reduce from 87% to 40%.

FIGURE 5.1

Primary energy supply by source



Historical data source: IEA (2023)

5.1 Coal

Between 2000 and 2010, there was a substantial surge in coal demand, rising at an annual growth rate of 10%, from 1,351 Mt to 3,526 Mt. More modest growth followed over the next decade, with demand reaching 4,100 Mt by 2022, followed by a 5% leap in 2023 (IEA, 2023). We forecast a minor uptick in total coal consumption over the next two years before falling by a third by 2040 and ending at some 25% of peak coal use by 2050.

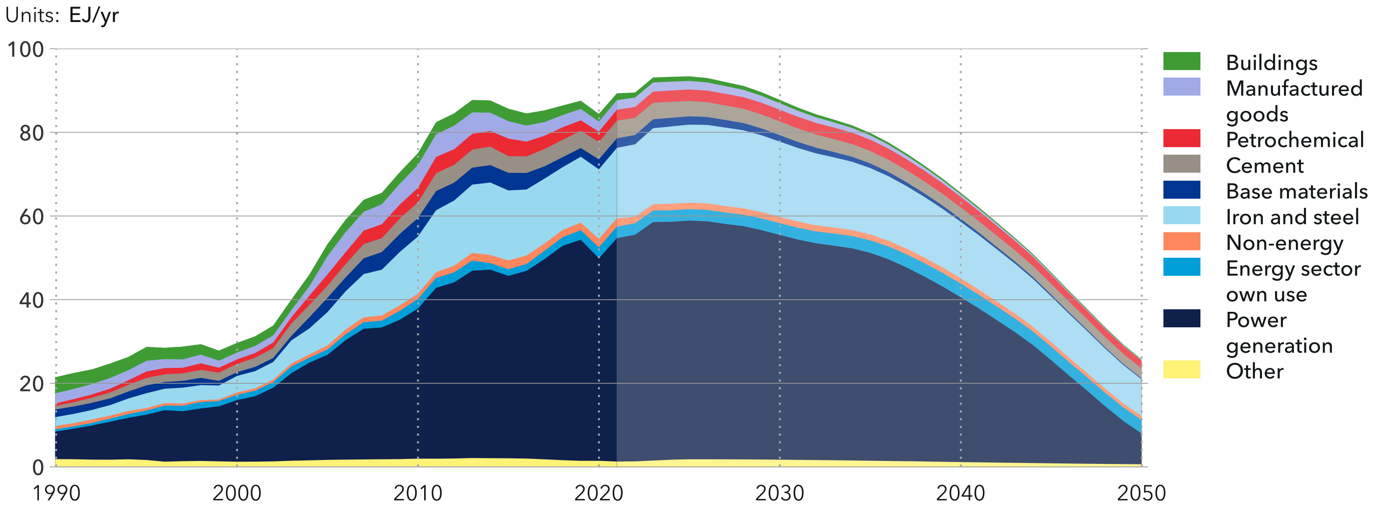
In 2023, China prioritized short-term energy security to avoid a recurrence of the power shortages that occurred in 2021 and 2022. This led to an increase in thermal coal imports, with shipments from Indonesia up 65.9% year over year to 89.9 Mt, Russian shipments increasing 88.7% to 18.3 Mt, and Australian supplies rising from zero to 11.2 Mt (Chen, 2023).

In our ETO, we forecast a minor increase in total coal consumption over the next two years before a decline to 3,005 Mt by 2040 and to 1,176 Mt by 2050. Anticipating the decrease in coal-based power generation and the swift expansion of renewable energy sources, coal plants will experience reduced revenue due to lower utilization. The National Development and Reform Commission (NDRC) has therefore developed mechanisms to compensate coal power plants for losses as they adjust to their new role as backup suppliers (Hove, 2023).

China's rapid additions of new coal-fired power plants and its lack of a coal phase-out plan are responsible for it falling behind the Paris Agreement pace, despite the country's record buildout of renewable energy (Xue, 2023). In 2021, China's President Xi Jinping stated that the country would start 'phasing down' coal use starting in 2026 as part of its effort to slash carbon emissions and reach carbon neutrality by 2060. However, China has been adding coal capacity at a record pace: in 2022, 86.6 GW of new coal-fired power plant capacity was approved compared with 18.6 GW in the previous year (Energy Foundation China, 2023), and in the first half of 2023 an average of two plants per week were approved, adding 52 GW of new coal-fired capacity. As of Nov 2023, 209 new coal power plants are either under construction or permitted in China, which accounts for 72% of the world's planned yet unbuilt capacity (Myllyvirta, 2023).

FIGURE 5.2

Coal demand by sector



Historical data source: IEA WEB (2023), US DOE (2010), Heat Roadmap Europe (2015)

In 2021, China announced it would stop financing and supporting technology for coal plants overseas. This is an important step that increases the costs of new coal-fired generation in other regions and helps the transition to cleaner technologies. According to Global Energy Monitor, overseas coal project financing by China in 2022 had fallen 78-fold since its peak at USD 39bn in 2017 (Hurley & Tate, 2023).

On the demand side, the power generation and manufacturing sectors are the major coal consumers in China. According to our Outlook, coal consumption in both sectors will continue growing for the next two years. Coal's share in electricity generation will reduce from 60% today to 3% in mid-century. The electrification of China's manufacturing is projected to decrease demand from 29 EJ in 2022 to 13.6 EJ by 2050, with iron and steel production expected to constitute the highest share of coal demand at 35% in 2050. However, the economic appeal of transitioning to electric arc furnaces (EAF) is hindered by the relatively new status of many basic oxygen furnace (BOF) facilities in China, as mentioned in Chapter 3, Manufacturing. Towards the end of the outlook period, iron and steel (9 EJ/yr) will overtake power generation (7 EJ/yr) as the largest consumer of coal in China. Coal use in buildings, which is relatively small, will fall in the coming years to be largely replaced by natural gas. Coal demand in non-energy (feedstock) remains quite stable.

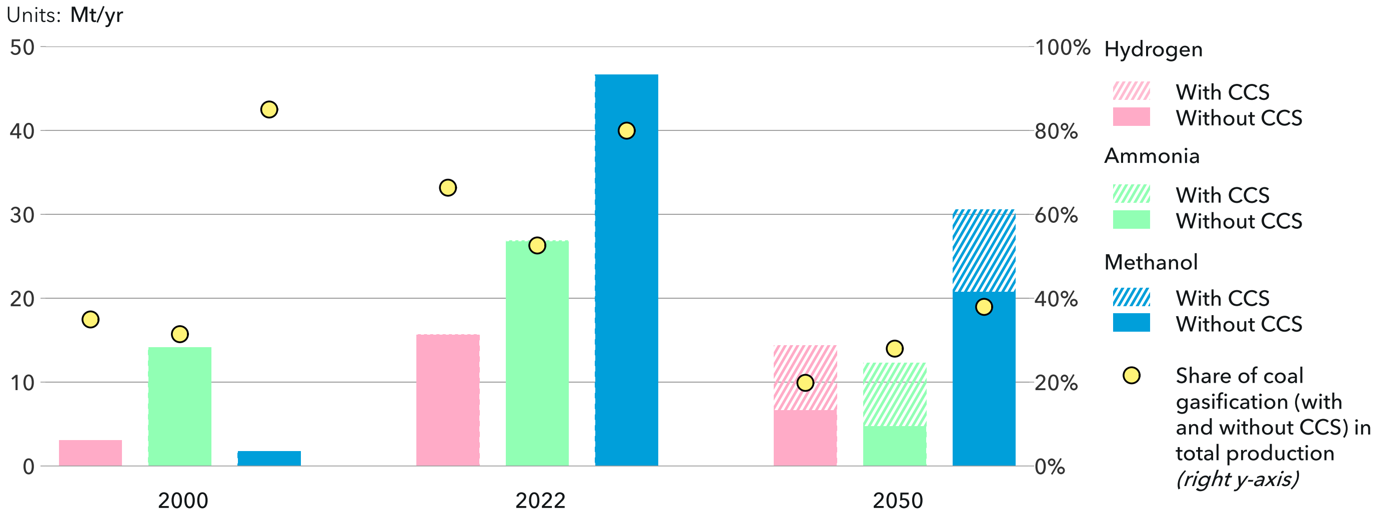
In China, over the past two decades, coal gasification has played a pivotal role in producing methanol, ammonia, and hydrogen (as feedstock). As of 2022, coal fuelled approximately 66% of the hydrogen (as feedstock), 52% of ammonia, and 80% of methanol production in the country. China stands as the sole nation producing hydrogen from coal on a substantial scale, contributing 24% of the world's hydrogen supply. However, this production process is notably emissions-intensive. To fulfil China's pledge of reaching peak emissions before 2030 and achieving carbon neutrality by 2060, coal gasification processes require carbon capture and storage (CCS) units to mitigate emissions. Figure 5.3 outlines the production of methanol, ammonia, and hydrogen (as feedstock) both with and without CCS in 2000, 2022, and 2050.

If China's coal use follows the path in our forecast, the resulting annual emissions from coal will fall from 8 GtCO$_2$ in 2022 to 1.8 GtCO$_2$ in 2050, making a crucial contribution to reducing global emissions. Yet, China's coal-related emissions, comprising 11% of global energy-related emissions in 2050, stand as a significant barrier to achieving worldwide net-zero emissions by mid-century. To achieve the 1.5-degree Celsius target, the share of coal in China's power mix must be significantly reduced to single digits by 2035, and a complete phase-out of coal should be considered by 2045, as outlined in our *ETO Pathway to Net-Zero Emissions report* (DNV, 2023b).

> By mid-century, the share of coal in iron and steel production surpasses that in the power sector, reaching 35%.

FIGURE 5.3

Hydrogen, ammonia, and methanol production via coal gasification



5.2 Oil

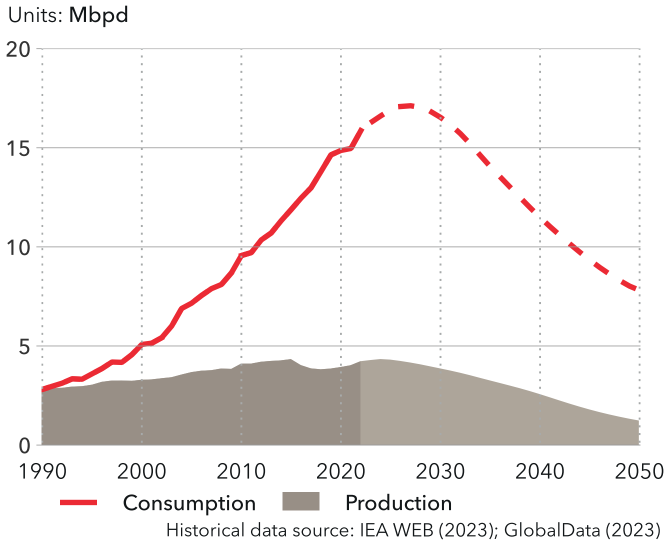
For almost three decades, oil has been the second-largest contributor to China's energy supply, with its share in primary energy supply rising from 18% in 1996 to 21% by 2022. We forecast this share will persist until 2027 before gradually declining to 11% in 2050.

China relies heavily on oil imports to supplement domestic production. In 2022, China's oil production and demand were about 4 Mbpd and 16 Mbpd, respectively. As oil demand has increased about 5% per year over the last two decades, the share of imported oil has increased from 37% to 75%. Figure 5.4 shows historical and forecast oil production and consumption. Over the past decade, around 50% of China's imported oil originated from Russia and Saudi Arabia. Following the Russian invasion of Ukraine, adjustments in oil pricing led China to restructure its crude oil imports. In 2022, crude oil imports from Russia increased 8.2%, according to China's customs data. In 2023, due to refinery expansions in the country and initiatives to reopen the economy after the government eased COVID-19 mobility restrictions, record volumes of crude oil were imported into China.

Driven by the ever-increasing demand for transport, due to population and economic growth, oil demand rose steadily by about 5.6% per year between 2002 and 2022, from 5.4 Mbpd (12 EJ) to 16 Mbpd (33 EJ), despite temporary dips like those in 2008 and 2020. We anticipate oil demand to increase to 17 Mbdp (35 EJ) in 2025, but then to plateau until 2030 before declining by 71% to 8 Mbpd (16 EJ) in 2050.

FIGURE 5.4

Oil production and consumption



Historical data source: IEA WEB (2023); GlobalData (2023)

As shown in Figure 5.5, oil demand in the transport sector has increased from 5.3 EJ in 2002 to 16.5 EJ in 2022, a 5.8% CAGR. We forecast the demand to peak at about 17.6 in 2025 before it decreases by 74% to 4.6 EJ in 2050 due to the significant rate of electrification in the road subsector. The surge in passenger new energy vehicles (NEV) in 2022 pushed their market share to 27%, a significant leap from 14% in 2021. This share will continue to grow to 45% of passenger vehicles and 13% of commercial trucks and vans in 2025. The trend will deepen in the coming decades to the point where passenger and commercial vehicle oil demand will decline by 97% and 85%, respectively, by 2050. Oil use in aviation, shipping, and rail transport (collectively termed 'other transport' in Figure 5.5) will initially grow for a few years. Thereafter, the shift toward biofuel, green ammonia, e-kerosene, and other low-carbon fuels will reduce this oil demand by 28% from 5.3 EJ in 2022 to 3.7 EJ in 2050. Detailed information and analysis of transport fuels is set out in Chapter 3.1, Transport.

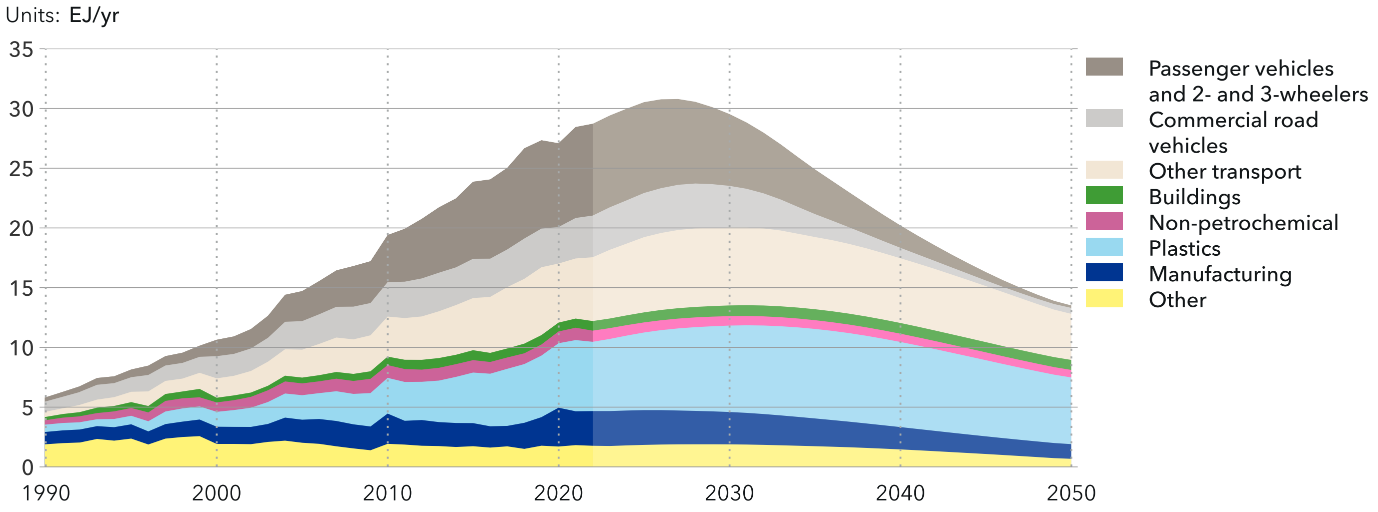
Oil's second largest sectoral demand is as feedstock for non-energy, plastics, and non-petrochemical production, which do not entail any direct CO_2 emissions. Oil demand in non-petrochemical (such as bitumen), which has been around 1 EJ in the last decade, will drop by 40% toward the mid century. By contrast, oil demand for plastics has doubled, from 3 EJ in 2012 to 6 EJ in 2022, and the growth will continue to 7.5 EJ around 2035 then slowly decline to 5.6 EJ/yr by 2050, due mainly to a decrease in plastics production caused by demand-side reduction and substitution measures as well as higher rates of recycling (see Chapter 3.4, Non-Energy Demand for more details). However, with declining oil use for most energy purposes, the share of non-energy use in oil demand rises from 23% today to 46% in 2050.

The third largest sector in terms of oil use is manufacturing, which is anticipated to reduce its oil demand by one third compared with its 2022 value of 3 EJ by the middle of the century, while maintaining a consistent share of around 9% of oil demand. Oil or its products are also used in buildings, power, 'other' sectors, and for producing the oil itself. Nevertheless, these uses are small (9% of total oil demand) and remain so throughout our forecast period.

In 2028, the share of plastics production in oil demand increases to 23%, surpassing both passenger vehicles and aviation. By 2050, the share of plastics will be 42%.

FIGURE 5.5

Oil demand by sector



Historical data source: IEA WEB (2023)

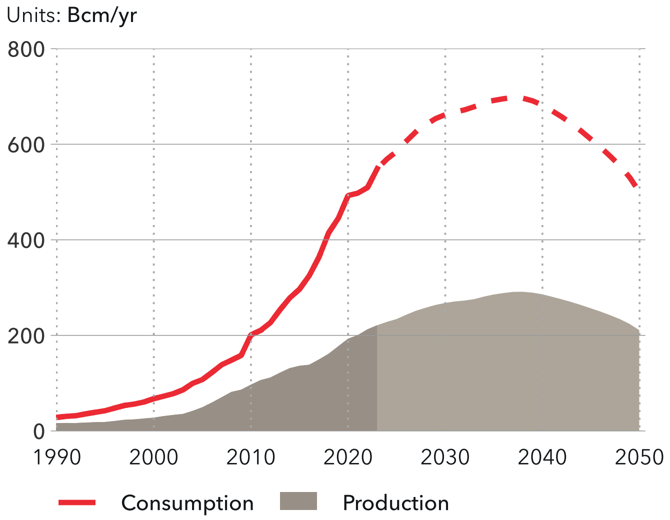
5.3 Natural Gas

Between 2010 and 2020, China's natural gas consumption expanded significantly from 201 billion cubic metres (bcm) to 493 bcm, averaging an annual growth rate of approximately 10%. Consequently, during this period, the share of natural gas in the primary energy supply doubled, rising from 4% to 9%. We forecast growth to continue until the mid-2030s, but at a much lower rate, about 2.1% per year, reaching around 700 bcm before it declines to 500 bcm in 2050.

The surge in demand for natural gas in China stems from the government's initiatives to diversify the energy mix and reduce air pollution, driven by environmental and climate factors favouring the lower carbon intensity and higher combustion efficiency of gas over coal. To meet this escalating demand, China advanced the construction of its 'national network' of gas infrastructure, increasing the total length of long-distance natural gas pipelines by more than 3,000 kilometres and gas storage capacity by approximately 5 bcm. The country made progress on several large liquefied natural gas (LNG) projects, including putting the Binhai LNG terminal into operation and building the Beijing Gas and Caofeidian LNG terminals (*China Gas*, 2023). Figure 5.6 provides an overview of production, consumption trends. Note that natural gas in our ETO is the chemical energy content of hydrocarbon gases including both 'associated' and 'non-associated' gas including natural gas liquids (NGLs), and coalbed gas.

FIGURE 5.6

Gas production and consumption

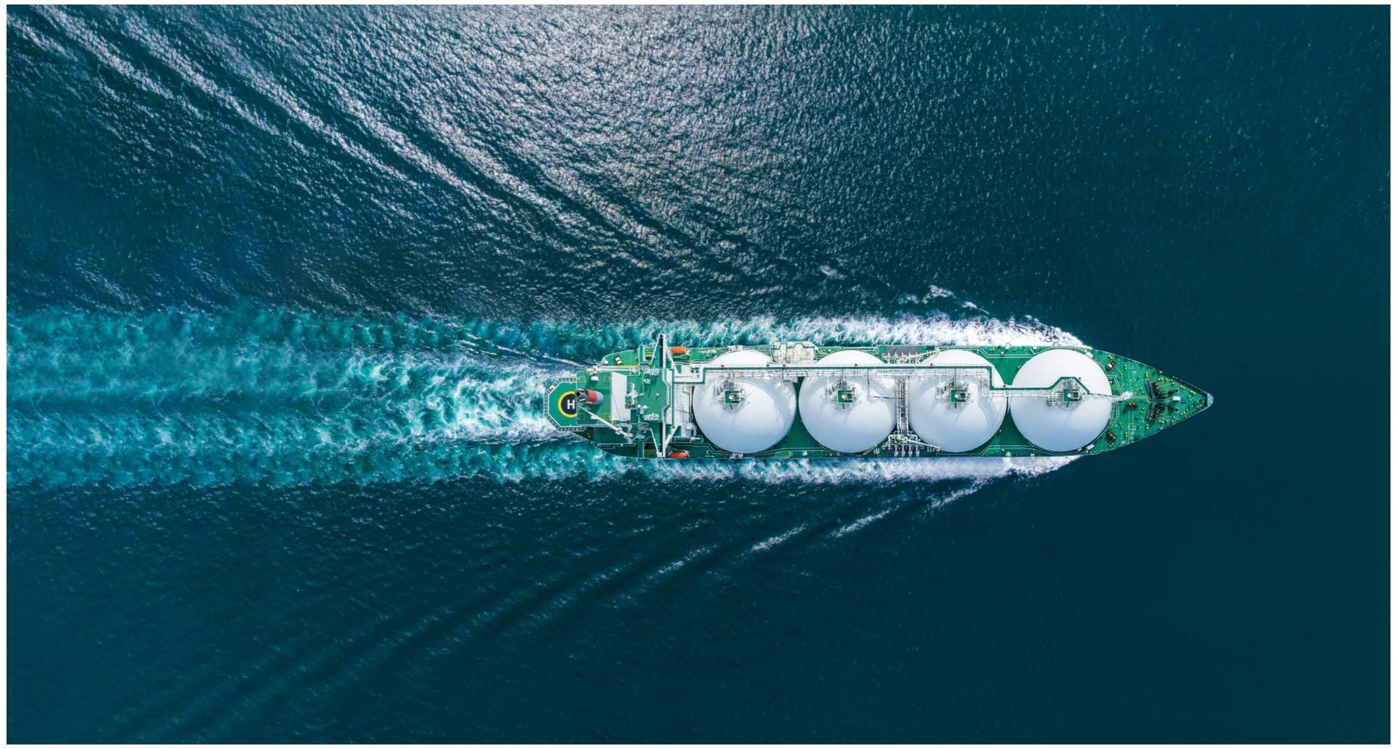


Historical data source: IEA (2022); GlobalData (2021)

In 2022, China's natural gas demand was 14 EJ, and according to the *China Natural Gas Development Report* 2023 from the National Energy Administration, it has experienced a 6-7% increase in 2023.

As shown in Figure 5.7, there has been a shift in natural gas usage over the years in different sectors. Since 2021, the power sector has surpassed the buildings sector as the primary user, accounting for 26% of natural gas consumption, 4.5 EJ, in 2022. Demand for natural gas in the power sector will rise to to 9.2 EJ by 2038, primarily owing to its role in replacing coal-fired power. However, following this peak, the demand is expected to gradually diminish to 7.4 EJ as the proportion of renewable energy sources in the power sector expands. The demand in the manufacturing and industry's own use remains around the current value of 4 EJ and 2.5 EJ respectively until about 2040, before it reduces to 2.5 EJ and 1.6 EJ, driven by improved energy efficiency and increased electrification. Note that some own use in the energy sector will be for liquefaction and regasification of gas that is transported as LNG. Gas demand in the transport sector will increase by 40% in 2037. Thereafter, it will decline by 95%, compared with the 2022 value, due to its increasing displacement in its main application, shipping, by the rise of hydrogen derivatives such as ammonia and e-fuels.

This general decline in gas use is partly offset by higher demand in buildings and non-energy sectors. In the buildings sector, the demand will rise by 74% from 4.3 EJ in 2022 to 7.4 EJ in 2050, primarily driven by gas substituting traditional biomass in various applications.

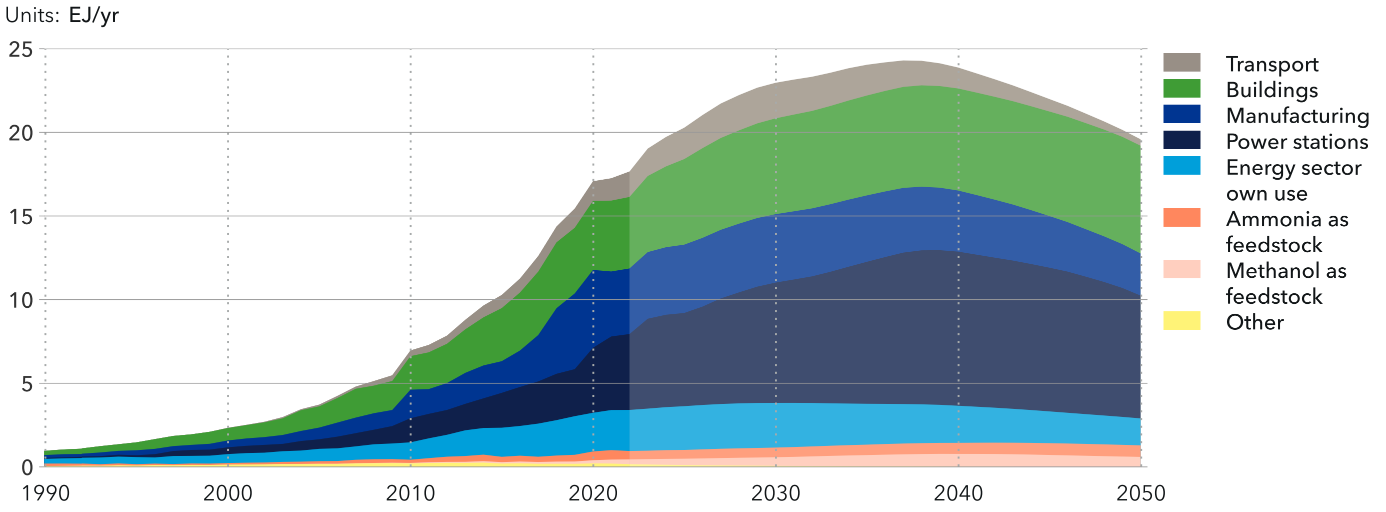


Similarly in the non-energy sector, due to the increase of ammonia and methanol production as feedstock, the demand will increase by 43% from 0.9 EJ in 2022 to 1.3 EJ in 2050.

As shown in Figure 5.6, in the last two decades, natural gas production in China has increased. According to the *China Natural Gas Development Report* 2023, for six years in a row, China has increased domestic gas production by more than 10 bcm. In 2022, China produced 220 bcm of gas, an increase of 6% over 2021 (*China Gas*, 2023). In 2023, the Comprehensive Department of the National Energy Administration implemented a new revision of the *Natural Gas Utilization Policy* to promote the high-quality development of the natural gas industry (China Energy News, 2023). We forecast the production to peak around 292 bcm in 2037 before declining to 211 bcm in 2050.

FIGURE 5.7

Gas demand by sector



Historical data source: IEA WEB (2023)

Despite the country's strategic focus on further developing its natural gas infrastructure and enhancing domestic production capabilities, China's demand for natural gas continues to outpace its domestic production capacity. For example, in 2022, more than 40% of primary gas supply was imported. Figure 5.8 shows regional historical and forecast gas imports to China via pipeline and as LNG. We expect an increase in imported gas in the coming decade, followed by a steep decline through to 2050 as the consumption of natural gas reduces.

Except for a relatively small and consistent quantity of 4 bcm imported from South East Asia, the majority of gas imports via pipeline into China originate from North East Eurasia. In 2022, pipeline imports from North East Eurasia grew by 7.8% year-on-year to 62.7 bcm. The 54% jump in imports from Russia – from 10.4 bcm to 16 bcm – was one driver of this growth, as Russia continues to increase deliveries to China through the Power of Siberia pipeline, which is expected by Moscow to reach its capacity of 38 bcm by 2025 (*China Gas*, 2023). Until 2016, China imported LNG mostly from South East Asia and the Middle East. However, since 2017, Australia has been the main provider of LNG to China. In 2022, China's LNG imports declined by 19.5% to 87.6 bcm. It was the biggest year-on-year drop since China began importing LNG in 2006, likely caused by slower economic growth, COVID-19 restrictions, and high LNG spot prices.

Underground gas storage

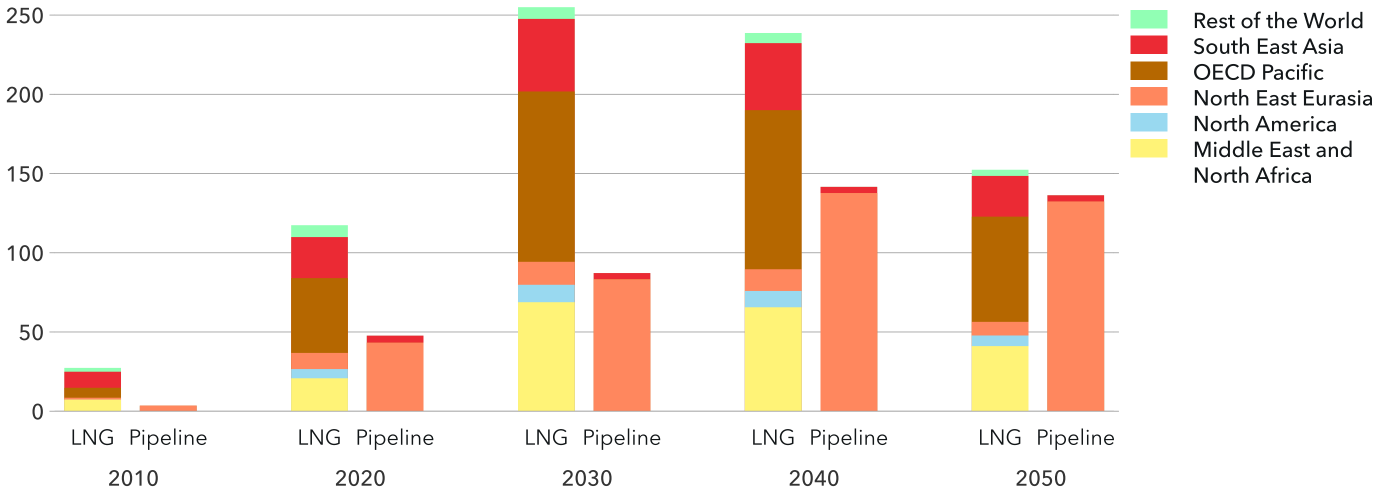
Natural gas is injected into underground storage (salt caverns, aquifers, or depleted fields) when demand is lower (summer) and withdrawn when gas demand for space heating increases (winter). China has been investing in underground gas storage facilities to enhance energy security by providing a buffer against supply disruptions and seasonal variations in gas demand. By December 2022, China has 84 underground gas storages in operation. These underground storages are able to supply 19.8 bcm peak-shaving natural gas. To ease the seasonal gas shortage, over 43 new underground gas storages are planned with effective peak-shaving capacity announced to be over 61.5 bcm (ARA, 2023). By 2050, about 50% of hydrogen capacity is repurposed methane storage sites.

> Despite China's strategic focus on further developing its natural gas infrastructure and production capabilities, its demand for natural gas continues to outpace its domestic production capacity, leading to a more than 50% reliance on imports to fulfill its energy needs.

FIGURE 5.8

Gas import as LNG and via pipeline by region

Units: Bcm/yr



5.4 Solar

We forecast that renewable generation from solar PV will continue increasing and account for 38% of all electricity produced in China in 2050. More than a third of solar capacity installed will be combined with storage, mainly batteries. This dramatic growth will be driven by the low cost of solar energy and continued policy support.

Generation and capacity
China has grown its solar industry steeply over the last decade: from less than 1% of the power mix in terms of total generation in 2015 to around 5% presently. Given that the total electricity demand has increased by half over the same period, this five-fold growth in solar is moderate. However, at present, solar is the third largest renewable source in the power sector in China after hydropower and wind. Furthermore, we forecast that renewable generation from solar PV will continue increasing and will surpass hydro in terms of generation share by 2030.

From 2026, solar will temporarily surpass wind through to 2040, when wind will catch up and go hand in hand with solar as the two dominant sources of renewable power through to 2050. By 2050, solar PV will have grown 14-fold from today's levels, and will account for 34% of all electricity generated in China.

The growth in solar has been largely driven by subsidized electricity prices (in the form of feed-in tariffs or FITs) for renewable energy. As part of FITs mechanism, solar and wind firms were offered a guaranteed price above market for their electricity. Since FITs greatly reduced the risks associated with the novel technology, this policy measure attracted many new developers into solar industry. The success of the FITs policy has been a dramatic decrease in the costs of solar energy, which is already now the most economical form of energy in China on a levelized cost of electricity (LCOE) basis.
In fact, due to solar achieving the grid-cost parity, China's government started phasing out central subsidies starting 2022.

The policy support for solar will however continue, although in new forms. For example, provincial subsidies will continue fuelling new solar installations. China's aspirations for green energy are aligned with its efforts towards meeting dual carbon goals announced in 2020: achieve peak CO_2 emissions before 2030 and carbon neutrality by 2060. As part of these efforts, China set a target to reach 1,200 GW of its energy through solar and wind combined by 2030. With new solar installations concentrated in the country's north and north-west provinces (such as Shanxi, Xinjiang, and Hebei), a significant potential for rooftop solar roll-out in Central and East China, as well as large solar stations being built in the Gobi Desert (Jaghory, 2022), we expect China to reach this target ahead of the announced deadline.

By 2050, or 34%, of solar will be combined with storage, mainly battery, providing greater asset values, flexibility, and cost advantages. The increase in solar will be accompanied by a corresponding dramatic decrease in fossil-fuelled generation, which will drop from 66% today to only 7% in 2050 (Figure 5.9). Other non-fossil plants, including wind, together will contribute almost 55%. In other words, by 2050, we expect substantial transformation of China's energy mix from fossil dominated to a much cleaner one.

Such growth is possible first and foremost due to continuing increase in electricity demand in China – driven by electrification of all major demand segments, including road transport, buildings, and manufacturing – and by the emergence of new demand segments such as grid-connected electrolysis. This expected growth in electricity demand will drive new power plant capacity investment. Of this new capacity, solar will account for 58% between now and 2030. In other words, for each 1 GW of new capacity added in the years 2023 to 2030, 0.58 GW will be solar. This is because, on average, solar already has the lowest LCOE. The cost learning curve effects applicable globally for solar energy will improve solar economics even further.

In 2011, new solar capacity additions exceeded 1 GW/yr for the first time and grew increasingly thereafter, breaking through 10 GW/yr in 2013 and 30 GW/yr in 2016. Accordingly, the total installed grid-connected capacity in 2022 exceeded 300 GW compared with just above 1 GW in 2011. We forecast that annual solar capacity installations will continue to rise, nearing 200 GW by 2050.

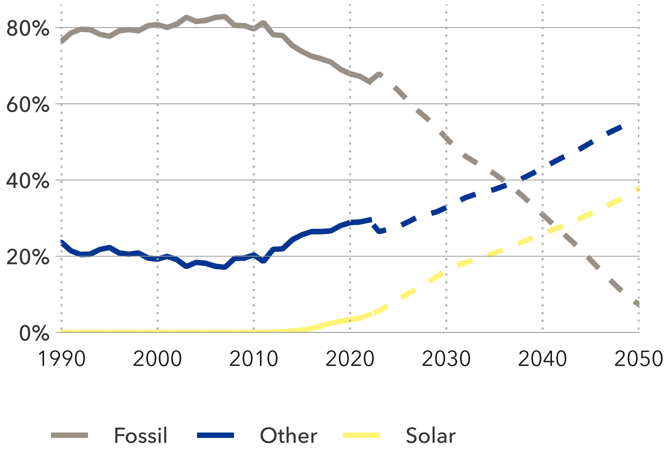
As more storage capacity is added worldwide, storage costs decline as well, helping to drive cost learning.
As a result, the share of solar PV systems with dedicated

> The share of solar PV systems with dedicated storage will rise to about 7% of all solar installations by 2030. It will continue rising to reach about 50% in the 2040s and close to 100% by 2050.

FIGURE 5.9

Share of solar, fossil, and other non-fossil fuel in grid-connected generation

Units: Percentages

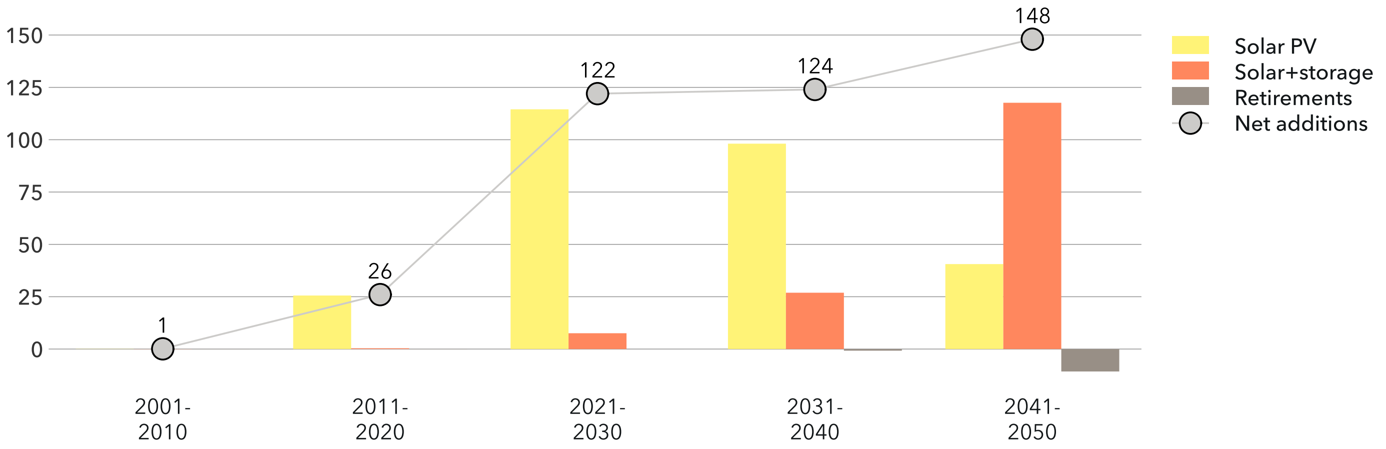


Historical data source: IEA WEB (2023)

FIGURE 5.10

10-year average solar capacity additions and retirements

Units: GW/yr



Historical data source: GlobalData (2023) storage will rise to about 7% of all solar installations by 2030. It will continue rising to reach about 50% in the 2040s and close to 100% by 2050 (Figure 5.10). As increasing amounts of solar PV electricity are grid-connected, the additional benefits of a near fully flexible storage system co-located with solar PV will be an important driver for solar+storage investments.

By mid-century, total installed capacity will reach 3.9 TW for solar PV and 1.6 TW for solar+storage. The 5.5 TW of combined solar capacity projected for 2050 is nearly 13 times the level seen in 2022. Nearly a half of all installed capacity in China in mid-century will be solar (Figure 5.11). In addition to grid-connected solar, we expect about 1.3 TW of off-grid capacity dedicated to satisfying electricity demand for hydrogen production through electrolysis; a dramatic increase from only about 0.9 GW installed now.

Economics

Favourable economics are essential for continued growth in solar capacity. The LCOE for solar PV is currently around USD 39/MWh, which is the lowest among all fuel options in the power sector. For solar+storage, it is almost twice as much at USD 75/MWh, though this is still more competitive than any fossil-fuel based option and only slightly less competitive than fixed offshore wind. As new installations continue rolling out in both China and globally, technological learning effects will drive down unit investment cost and reduce solar LCOE still further. The learning effects will also apply to battery costs which will further reduce the levelized costs of solar+storage. Therefore, in the long-run, the costs of solar energy will continue their declining trend. By 2050, we expect LCOEs as low as USD 24/MWh and USD 44/MWh for solar PV and solar+storage, respectively.

Another important aspect of solar economics is capture price. Our ETO model follows levelized profitability accounting for both price and costs. This approach better reflects the competitiveness of generation technologies as investment choices, given that some, such as solar PV, are fundamentally variable. Solar PV in China currently receives a capture price of USD 144/MWh. Solar+storage already has some capture price advantage over regular solar PV today. But over time, as the share of variable renewables in the power mix increases, the capture price advantage of solar+storage increases even further, and surpasses the cost disadvantage. Figure 5.12 shows the widening gap between capture prices and the narrowing gap between LCOEs for the two solar technologies.

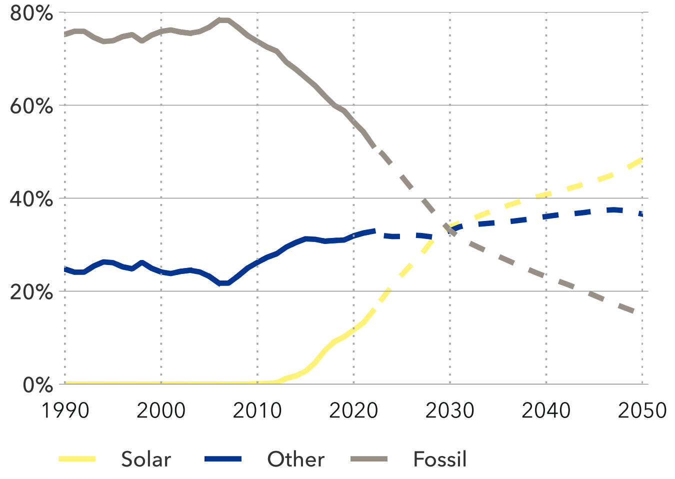
Figure 5.12 also shows that capture prices for solar decline somewhat from current levels but remain mostly stable and above LCOEs from the late 2020s. Lower capture prices will not, however, hinder the strong growth of solar PV. The portrayed prices and costs are averaged across the projects in China, and with prices reported on an annual rather than hourly basis. Therefore, individual project costs can be well below the average values, thus yielding higher profitability. Moreover, PV and storage systems are increasingly designed as a 'package' that can produce energy on demand, just like hydropower, nuclear, or combustion plants. New business models will therefore incentivize capacity, reliability, and flexibility aspects of such combined systems for solar project investors.

Due to the intrinsic variability of solar, its average capacity factors are currently the lowest compared with other generator assets: 15% for stand-alone solar and 5% for solar+storage. However, as more solar capacity is installed and more flexibility options are developed (i.e. energy storage, new markets, and demand-response solutions), capacity factors will increase steadily in the next decade. At higher penetration levels of solar towards mid-century, the capacity factor of solar without storage will decline due to more capacity being online during hours when solar generation is plentiful and cheap and electricity demand is not proportionally as high. Yet, as the role of solar+storage in providing flexibility becomes even more important with the rising share of renewables in the power mix, its capacity factor will continue increasing to reach 17% in 2050.

FIGURE 5.11

Share of solar and fossil fuel in grid-connected installed capacity

Units: Percentages

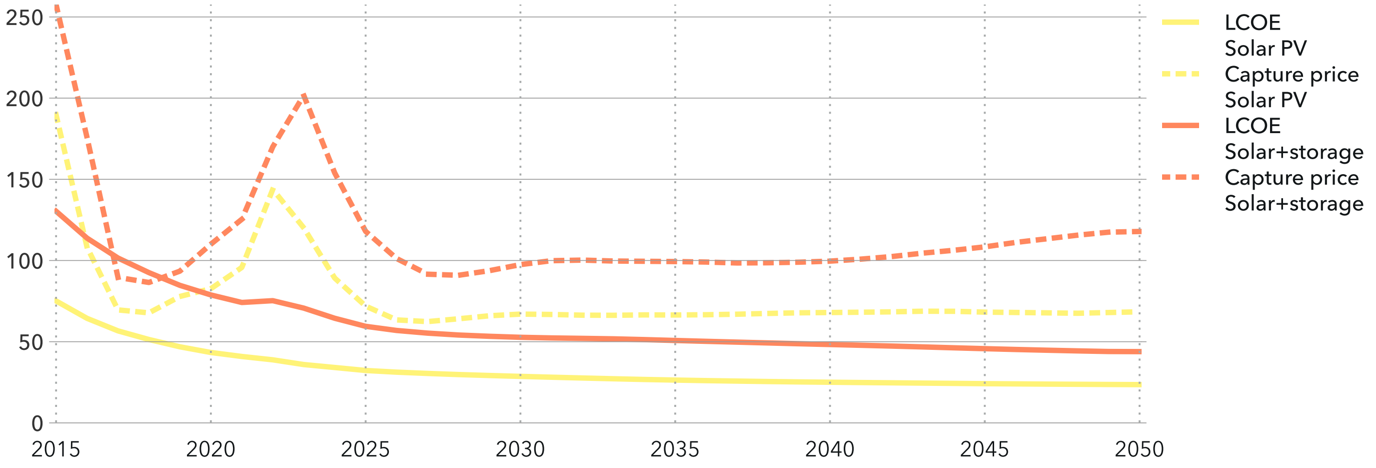


Historical data source: GlobalData (2023)

FIGURE 5.12

Solar levelized cost of energy and capture price

Units: USD/MWh



5.5 Wind

We forecast 1.5 PWh, or 13% of electricity, to be generated by wind alone in China by 2030. This will make wind the third-largest renewable power source after solar and hydropower. By 2050, wind will be on par with solar generating 6.2 PWh, or 38% of electricity, in the region.

The development of wind energy in China is an example of how a country can grow a new renewable energy industry at an astonishing rate in just over a decade. In 2010, wind made up only 1% of electricity generation in the region. Wind growth was sluggish during the first half of the 2010s; the share of wind in total generation increased only to 3% by 2015. However, a range of government policies, including generous subsidies in the form of FITs and regulations of provincial governments and generating companies (such as green electricity certificates and renewable portfolio standards), fuelled a steep growth in wind capacity by 2020. Between 2018 and 2022, China added more wind capacity than over the previous eight years.

As a consequence, today wind is China's largest source of energy after coal and hydropower, delivering almost 8% of the total electricity supply in 2022. Moreover, China's generation from wind accounted for 38% of global wind generation, making the region the world leader in this form of renewable energy.

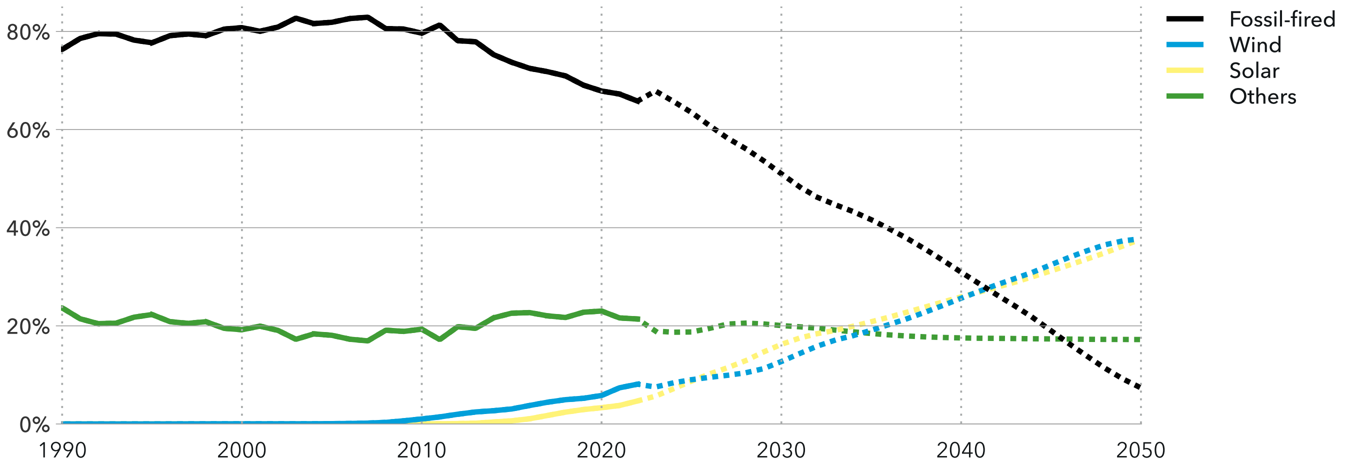
FITs were instrumental in boosting the roll-out of wind capacity since this policy mechanism reduced risks for wind energy producers at times when wind costs were high. Now, however, both wind and solar are approaching cost parity (and frequently superiority on a project basis) with other forms of generation. China's government has therefore announced the phase-out of central subsidies in 2021. However, wind energy remains crucial in delivering on China's commitment to meeting its dual carbon goals of achieving peak CO_2 emissions before 2030 and carbon neutrality by 2060. Thus, the support for wind will continue but will follow a new approach that relies more heavily on the policy support by provincial governments.

Given these policy aspirations as well as new onshore projects under construction in Inner Mongolia, Xinjiang, Gansu, and offshore projects along coastal areas, China is already set to reach its goal of 1,200 GW from wind and solar before the 2030 deadline. By 2030, we forecast 1.5 PWh, or 13% of electricity, to be generated by wind alone in China. This will make wind the third largest power source after hydropower and solar (Figure 5.13). By 2050, wind will be on par with solar generating 6.2 PWh, or 38% of electricity, in the region.

FIGURE 5.13

Share of technologies in grid-connected generation

Units: Percentages



Such a dramatic increase in wind generation will be enabled by strong growth in capacity throughout our forecast period. Figure 5.14 shows that during the 2010s, about 21 GW of wind capacity was added on average to the grid every year. We expect the onshore wind capacity additions to reach 44 GW/yr in the 2020s, to increase further to 85 GW/yr in the 2030s, and remain roughly around that level in the 2040s. Offshore wind capacity additions follow a similar trajectory, albeit at lower rates: 6 GW/yr in the 2020s, 16 GW/yr in the 2030s, and 19 GW/yr in the 2040s. These robust capacity additions are greatly facilitated by China already being a key player in the global wind supply chain.

The accelerated growth of wind power capacity is driven by both demand and supply forces. On the demand side, electrification of major demand sectors together with growth in grid-connected hydrogen electrolysis is expected to increase electricity demand in China by more than half by 2050. On the supply side, onshore wind is already cost-competitive against other power technologies; by mid-century, the costs of wind energy are expected to fall even further, with onshore wind becoming the cheapest source of power generation, and offshore wind remaining cost inferior only to solar PV (but not to solar co-located with storage).

Onshore and offshore wind

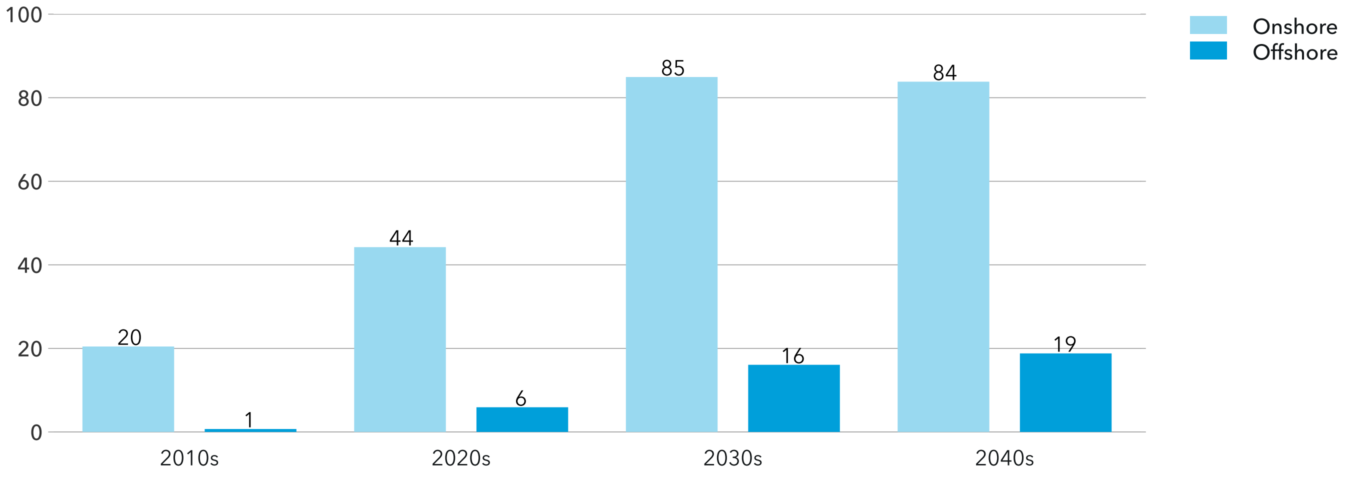
In this Outlook, we differentiate between onshore and offshore wind power, and within offshore, between fixed-bottom and floating foundations. Generally, fixed-bottom foundations are used for offshore wind wherever feasible, while floating foundations are required in deeper waters.

Thanks to the already-competitive costs of onshore wind, not only relative to offshore but also to most of the other power technologies, and thanks to the availability of land for installations, we foresee onshore wind to be the

FIGURE 5.14

Average wind capacity additions by decade

Units: GW/yr



primary form of wind power generation through 2050 in China (Figure 5.15). Even with the costs of offshore wind declining, onshore wind will be providing 86% of total wind power by 2030 and 77% by 2050. The share of fixed-bottom offshore generation in wind power will increase from 9% in 2022, to 13% in 2030, and reach 20% in 2050. The remaining 3% of wind generation in 2050 will come from floating offshore structures. We expect that offshore projects will not be limited only to wealthier coastal provinces such as Jiangsu, Zhejiang, and Shandong, but will also be pursued in Hebei, Liaoning, and Guangxi as indicated by the current pilots (Dedene, 2023).

Wind capacity dedicated to hydrogen electrolysis

In addition to grid-connected wind capacity, we forecast off-grid wind capacity dedicated to hydrogen production by electrolysis. In the near term, it is expected that hydrogen will only start replacing a modest share of the coal and gas use in manufacturing: 33% of reduction in coal and gas use between now and 2030 will come from the increase in hydrogen use. Therefore, in 2030, we forecast dedicated wind electrolysis capacity to reach only 4 GW, comprised entirely of onshore wind. *The Blue Book on the Development of New Power Systems* sets ambitious aspirations for scaling up the role of 'green' hydrogen or hydrogen produced within a low threshold of associated CO_2 emissions in end-use consumption in the later 2040s. Given these aspirations, we expect the dedicated wind electrolysis capacity to increase steeply towards about 187 GW of onshore wind and to be supplemented by an additional 14 GW of fixed offshore by 2050. The offshore wind-to-hydrogen pilot projects are already set in the near-term plans of, for example, Shanghai's municipal government (Martin, 2023).

Capacity factors

The capacity factors of wind turbines play an important role in wind power profitability and feasibility. Over the past two decades, continuous evolution in size and efficiency of rotors of both onshore and offshore turbines led to increased power generation even at sites with less favourable wind patterns. In 2022, the average capacity factor for existing installations for onshore wind stood at 24%. With prime onshore wind sites having already been utilized in China, further improvements in digital control and rotor design are expected to drive the capacity factors up to only 26% – a marginal improvement. Offshore, where wind sources are more constant and abundant, the projections for wind power are more optimistic due to the relative novelty of the market for this technology combined with continuing improvements in its core components. The current capacity factors for installed offshore turbines are already around 28%. Yet, higher capacity factors of new projects are expected to drive the offshore wind average up to 40% by mid-century.

Levelized cost of electricity

The accelerated roll-out of wind capacity in the past few years has led to a substantial reduction in costs. Figure 5.16 illustrates the development of LCOE for onshore and fixed offshore wind in China at the final investment decision (FID) years. The LCOEs pertain to new wind power projects coming online. Over the past 12 years, the costs have been decreasing consistently, driven by the effect of cost learning rates on turbine and other components. This decline, however, slowed down noticeably in 2022 due to supply chain issues that pushed component costs up.

Despite this recent deceleration, we forecast LCOEs for both onshore and offshore wind to continue declining, albeit more gradually. For onshore wind, the LCOEs are expected to drop from USD 40/MWh in 2022 to USD 29/MWh in 2030. Afterward, the slowdown in rotor size improvements and the less optimal locations being available for new installations decelerate the pace of the LCOE reduction even further. By 2050, we expect the LCOE for onshore wind to reduce to around USD 20/MWh redundant 2050.

The cost trajectory of fixed offshore wind generally exhibits a similar pattern: a rapid fall from 2010 to 2022 followed by a more gradual reduction. Figure 5.16 shows that the LCOE gap between onshore and fixed offshore wind narrows substantially over the entire period. Yet, even by the mid-century, fixed offshore will on average have almost twice the LCOE of onshore wind. The persistent cost differential between the two technologies is the result of some of the offshore wind-specific costs (such as construction and assembly, civil works, and grid-connections costs) remaining considerably higher even after reduction due to learning and scale effects.

Figure 5.17 focuses on the LCOEs of the two offshore wind technologies. Among all three wind technologies, floating offshore demonstrates a continuous dramatic reduction in costs, with the LCOEs leveling off only in the 2040s. In 2022, floating offshore exhibits LCOEs about four times as high as those of fixed offshore wind due to more costly floating structures and higher grid-connection costs. The cost reduction driven by learning and volume increases reduces this differential to about 40% by 2050.

It is worth mentioning that the described cost trajectories reflect annual LCOE averaged over the entire region. This means that some individual projects will have lower LCOE over a given year at the timescale of hourly or daily capture prices and, therefore, will be profitable. The increasing solar generation will amplify the role of wind even further: in the hours when solar electricity is unavailable, wind power will be rewarded at a premium price.

Challenges to wind power

An already rapid expansion and even further proliferation of wind capacity is contingent on several challenges being met. One of those is the integration of wind energy in grids in a manner that reduces curtailment risks. Other uncertain factors include outdated electricity grids and inflexibility in interregional transfer of energy. Most of the onshore wind projects are located in the north-western part of China, which is sparsely populated. On the other hand, the majority of energy is consumed in the east. This necessitates the long distance transmission of energy between the regions which leads to inefficiencies. These challenges, however, are not insurmountable and should not be regarded as showstoppers for wind.

FIGURE 5.15

Onshore and offshore wind grid-connected capacity

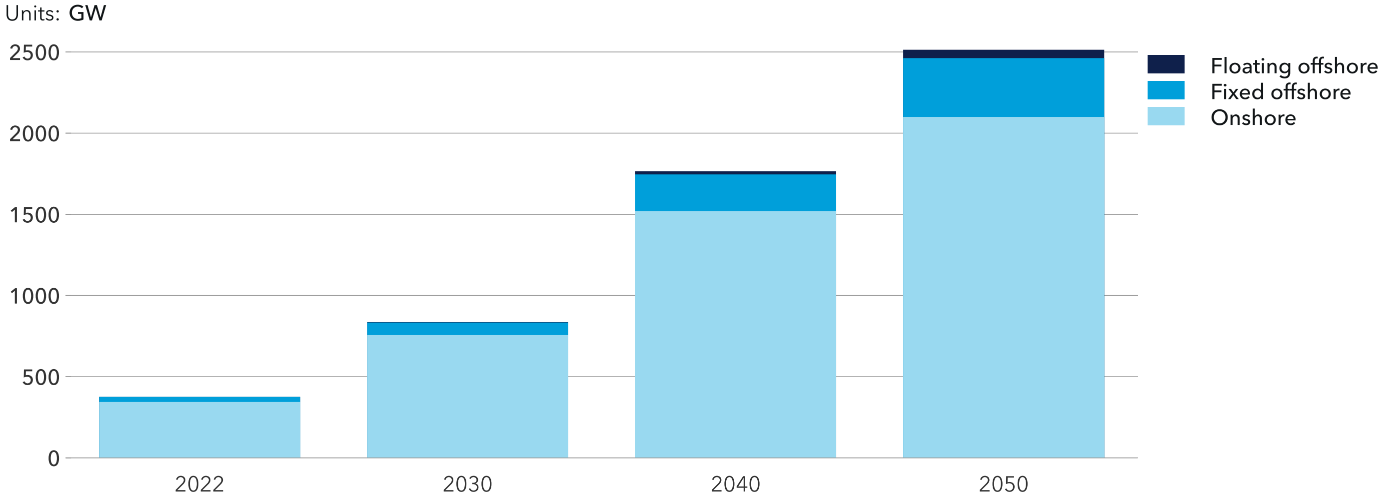
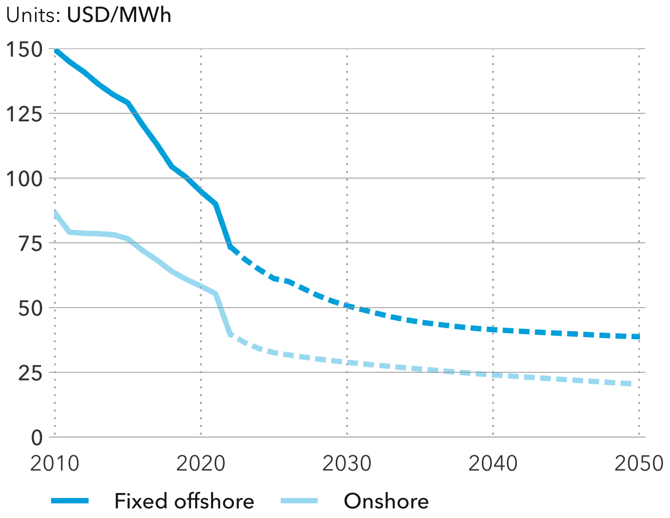


FIGURE 5.16

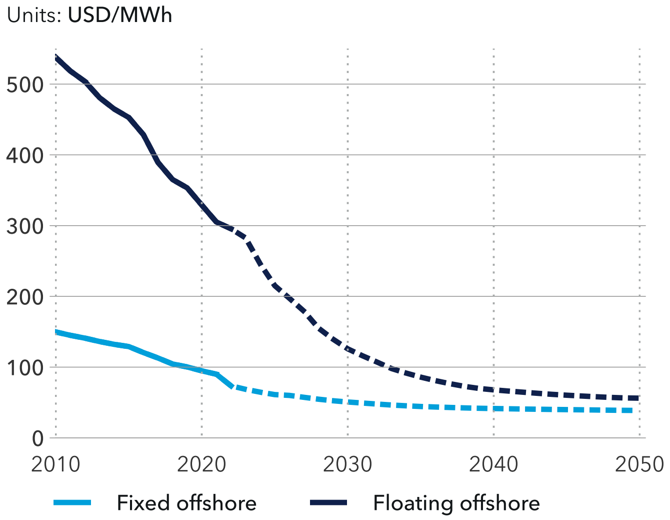
Onshore and fixed offshore wind levelized cost of energy



Historical data source: Global Data (2023)

FIGURE 5.17

Offshore wind levelized cost of energy, by technology



Historical data source: Global Data (2023)

5.6 Bioenergy

Bioenergy in China is expected to double by 2050, growing from 7 EJ in 2022 to 14 EJ in 2050, with its share in primary energy increasing from 4% to 10%. This growth will primarily be driven by bio-fuelled power generation, biomethane production, and applications in transport sectors, where bioenergy will play a niche, but important, role in decarbonizing hard-to-abate sectors.

Biomass in China has been and is still being used traditionally for residential heating and cooking, but over the last 20 years this share has decreased and we see that modern biomass applications are steadily taking over. The shift away from traditional use of biomass is driven by rising income levels and improved access to electricity, prompting a move towards more modern and efficient energy solutions. Modern use of solid biomass includes the use of agricultural and forestry residues, mainly for electricity production. This is the main driver for the uptake of bioenergy we see towards 2050. As of 2022, the power stations sector already accounted for 51% (3 EJ) of bioenergy demand in China. We project this to increase even further, reaching 58% (8 EJ) by mid-century.

Biomethane production is another sector where we forecast significant growth, from 4 PJ in 2022 to almost 3,000 PJ by mid-century. China's biomethane production is in its early stages of development, facing an inadequate industrial system and technical challenges. However, biomethane has great potential in China as the government supports projects promoting the valorization of waste as part of its financial plans for the development of rural areas (Air Liquide, 2022).

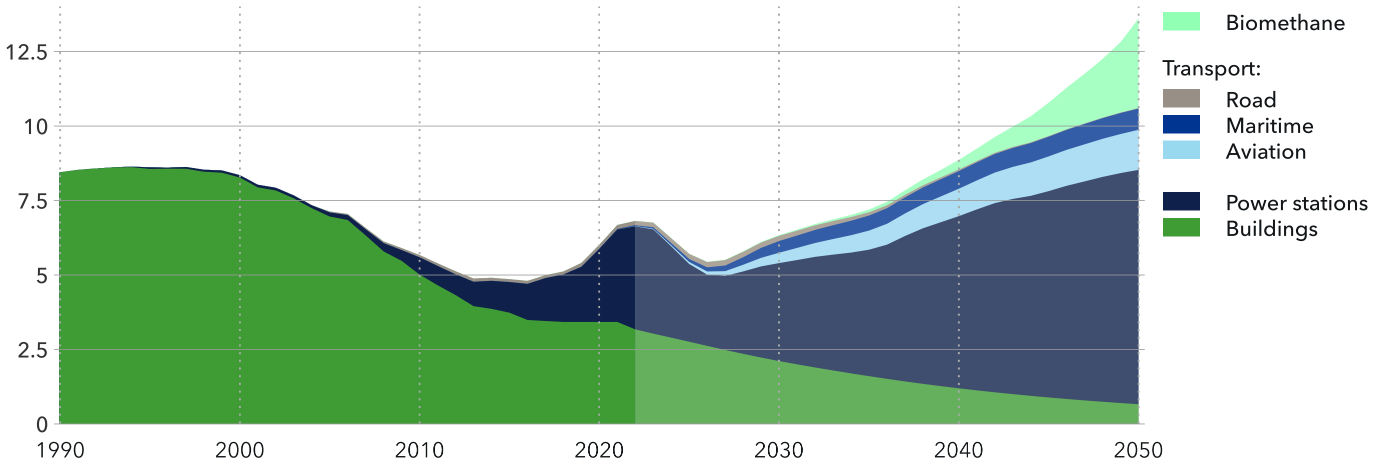
In the transport sector, liquid biofuels, particularly in aviation and maritime, will see an increase towards 2050 from the low share it currently has. Even though past government policies state biofuels are part of China's long-term strategic plan to protect the environment, conserve resources, and reduce dependence on imported energy, sparse policy support with little to no detailed implementation measures has kept consumption of biofuels low. To spur domestic production and consumption, the National Energy Agency (NEA) is urging local authorities to carry out demonstration projects and advising regional governments to provide financial support.

Biofuels in aviation are projected to grow from 11 PJ in 2022 to 1,300 PJ in 2050, accounting for 22% of aviation's energy demand. Recent advancements for aviation biofuels include the *14th Five-year plan for Bioeconomy Development* that encourages areas with good conditions to promote and pilot the use of biodiesel and advance the demonstrative use of aviation biofuels (DNV, 2023d). Biofuel in the maritime sector is expected to grow from 27 PJ to 700 PJ, accounting for 25% of maritime energy demand. In contrast, biofuels in road transport play a small role relative to electrification and we forecast a decreasing share of biofuels in road transport energy demand towards 2050 from the already small share it currently has. Figure 5.18 shows bioenergy demand in different sectors.

FIGURE 5.18

Bioenergy demand by sector

Units: EJ/yr



Challenges and opportunities

In China, modern biomass, as well as waste-to-energy feedstocks, are underutilized resources that will require new strategies to ensure sustainable exploitation. China has abundant resources of organic waste and annual production of animal waste and agricultural crop on its own has the potential of reaching 2.2 billion tonnes and 0.7 billion tonnes respectively. As of 2021, the country produced 6.3 billion tonnes of organic waste on average per year. The same year only 5% of organic waste was processed into bioenergy (State Council, 2021a), meaning the potential of expanding the bioenergy sector is extensive. More information about biomass potential and different feedstock is presented in DNV's recently released white paper *Biofuels in Shipping* (DNV, 2023c)

The development of waste-derived biogas and upgraded biomethane can help reduce reliance on fossil fuels, diversify energy sources, and curb carbon emissions. Therefore, China is stepping up its efforts in developing the biogas industry and is providing financial and administrative support to tackle technological barriers. In 2021, the Chinese National Development and Reform Commission, Ministry of Finance, and the NEA announced an additional CNY 2.5bn (USD 353m) in subsidies for biomass power generation, of which CNY 2bn was allocated for arranging non-competitive allocation projects (IEA, 2022). Moreover, according to a report from the Biomass Energy Industry Promotion Association (BEIPA), more support from the government is expected in the near future, estimating that CNY 1.2trn (USD 170bn) will be invested in the industry from 2021 to 2025 (State Council, 2021c). For renewable energy power generation projects, a tradeable green certificate can be applied, which means biomass power generation projects can obtain additional income through power markets and carbon trading and in this way improve operating conditions and increase profit as the carbon price rises.

China aims to achieve an annual output of biogas exceeding 10 bcm by 2025 and 20 bcm by 2030 (State Council, 2021d). Although China is stepping up its efforts in developing the biogas industry, it still faces several challenges. High costs associated with raw material collection, combined with a lower thermal generation rating compared with conventional energy sources like coal, have made government subsidies an important support for the industry's development. Moreover, the sector is hindered by technological barriers, lack of business models, high production costs, and low profit returns.

5.7 Nuclear

The development of nuclear power in China has been marked by significant growth and expansion and plays an increasingly important role in China’s energy system. Since 2010 the region has increased its capacity more than threefold, going from 15 GW to 55 GW by 2022. However, nuclear still only represents less than 3% of the primary energy mix.

As of February 2023, China operates 55 nuclear power plants with a total operational capacity of 57 GW. Additionally, there are 22 nuclear power units under construction, which will add another 24 GW of capacity by the early 2030s.

Beyond these, more than 70 nuclear power units are planned, which will contribute an additional 85 GW. This expansion places China first globally in both total installed nuclear power capacity and electricity generation from nuclear power, and by 2050 will account for over 25% of the world's nuclear fleet. This robust development is part of China's strategy to transition away from coal due to increasing concerns about air quality, climate change, and fossil fuel shortages. The China General Nuclear Power Group has set an ambitious goal of achieving 200 GW of nuclear power capacity by 2035, which would be achieved by adding 150 more reactors (Murtaugh & Chia, 2021).

Our Outlook reflects a general change in perspective with regions increasing focus on energy security. China in particular has intensified its focus on nuclear as a means of securing energy while reducing emissions and air pollution. Our forecast shows nuclear energy output growing slowly from today’s levels for the coming years, but accelerating from the late 2020s, see Figure 5.19. From today towards 2030, most of the added capacity will be based on traditional reactor technology and is already in the pipeline. Beyond 2030, additional capacity will be a mix between existing designs and new Small Modular Reactor (SMR) technology. Nuclear energy output peaks around 833 TWh per year by 2050, more than twice the current amount. By then, China will have the biggest nuclear energy output, representing 29% of global nuclear energy generation.

SMRs and other advanced reactors are designed to yield safer, more flexible, and potentially more cost-effective options than current nuclear power plants. Cost-effectiveness is especially important in Western developed economies such as Europe and North America, where the latest nuclear plants have suffered significant budget and schedule overruns. China has managed to build conventional nuclear faster with limited cost overruns (Rystad Energy, 2023). With significant future electricity demand, we expect a significant portion of nuclear power stations in China therefore to be based on conventional designs that have already been successfully built.

As for the development of SMRs in China, the overall research and development in China is very active, with over 20 different designs creating vigorous competition among companies and encouraging innovation.

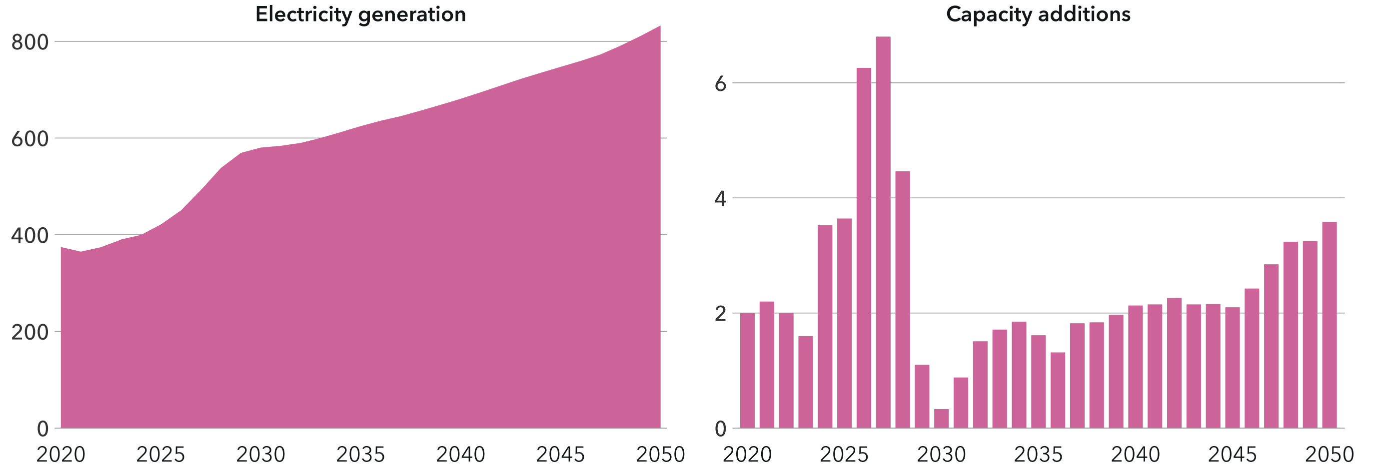
In 2021, one of the most advanced small modular reactor designs, a pilot 210 MW gas-cooled reactor (Gen IV) based on HTR-PM design (WNA, 2023), was successfully connected to the grid. Tests will continue with the aim of bringing 18 such HTR-PM units online (WNN, 2021). One reason for the interest in SMR development in China is because SMRs can easily slot into existing and decommissioned coal-fired power plants, where the heating units are seldom very large, usually under 500 MWe, and thus very well suited for SMRs to utilize a lot of existing infrastructure.

Another potential for SMRs in China is the development of small district heating reactors of 100 to 200 MWt capacity. There is a large potential estimated at around 400 units. The demand for buildings heat is very large in northern China. Many places still use coal which is causing serious pollution, particularly by dust, particulates, sulfur, and nitrogen oxides. The other source of district heating is based on natural gas, which is largely imported and subject to global gas price vicissitudes, and therefore subject to energy security risk.

FIGURE 5.19

Nuclear electricity generation and capacity additions

Units: TWh/yr (left); GW/yr (right)



5.8 Energy efficiency

China's journey towards energy efficiency is deeply rooted in its government's commitments, demonstrated through comprehensive policies, regulatory frameworks, and national targets. Looking ahead, China is poised for further reductions in energy intensity, delivering more energy services with less energy, although the rate of decrease is expected to slow down over time.

China's energy efficiency developments have been guided by a series of commitments by China's government, which manifested itself in a suite of specific policies, regulatory frameworks, and national targets. Central to this commitment are the objectives outlined in the country's *Five-year plans*, which consistently emphasize energy conservation and efficiency across various sectors and set specific targets, such as reducing energy consumption per unit of GDP.

For example, in the *12th Five-year plan* (2011-2015), China aimed for a reduction in energy consumption per unit of GDP by 16% from 2010 levels. It achieved this target, reporting a 18.2% reduction in energy intensity by 2015. The *13th Five-year plan* (2016-2020) set a goal to reduce energy consumption per unit of GDP by 15% from 2015 levels and to reduce carbon dioxide emissions per unit of GDP by 18%, both of which China achieved.

In the coming years, China's focus on energy intensity – defined as the amount of primary energy used per GDP unit – is expected to yield further significant reductions. The current rate of 4.5 MJ/USD is projected to decrease to 3.0 MJ/USD by 2035 and 2.2 MJ/USD by 2050. This downward trend, however, will moderate over time. The current annual decrease of 3% in energy intensity is anticipated to slow to 2% as 2050 approaches. Additionally, Figure 5.20 illustrates a broader transformation within China, marked by significant advancements in energy efficiency, a decline in GDP growth per capita, and a reducing population.

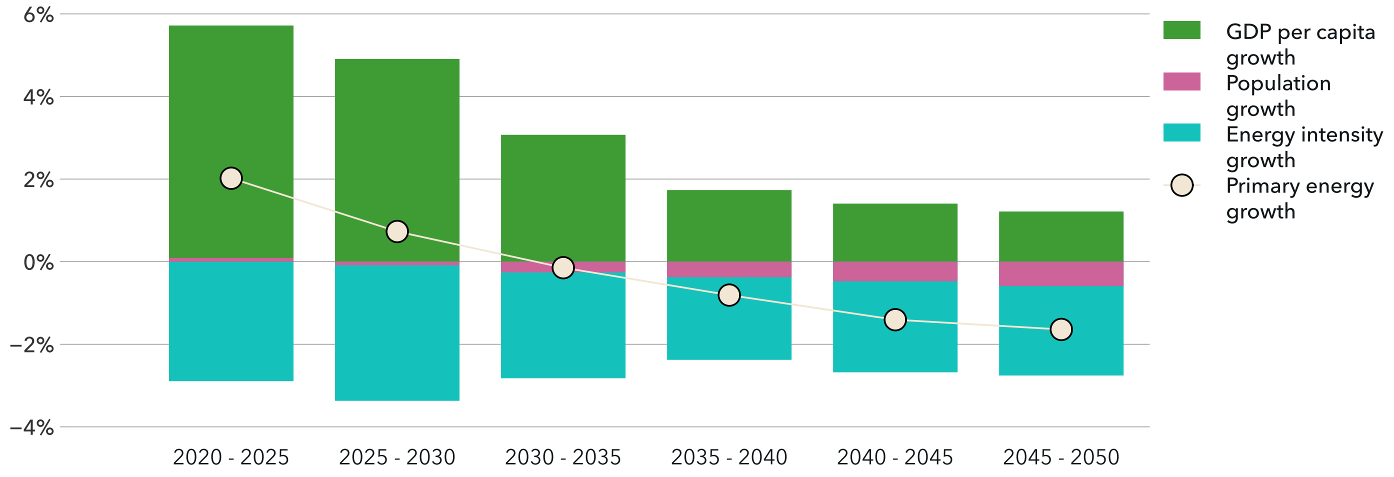
Sectoral developments

The *Energy Conservation Law* and *Renewable Energy Law* provide a robust legal framework supporting China's energy efficiency initiatives. These laws demand the adoption of energy-saving practices and are bolstered by programmes like the Top-1000 Energy-Consuming Enterprises Programme. This programme specifically targets major industrial energy consumers, encouraging them to adopt energy conservation measures. Collectively, these approaches aim to mitigate the environmental consequences of China's rapid economic expansion, fostering a path towards sustainable development.

FIGURE 5.20

Primary energy growth as a function of population, GDP/capita, and energy intensity improvements

Units: Percentages/yr



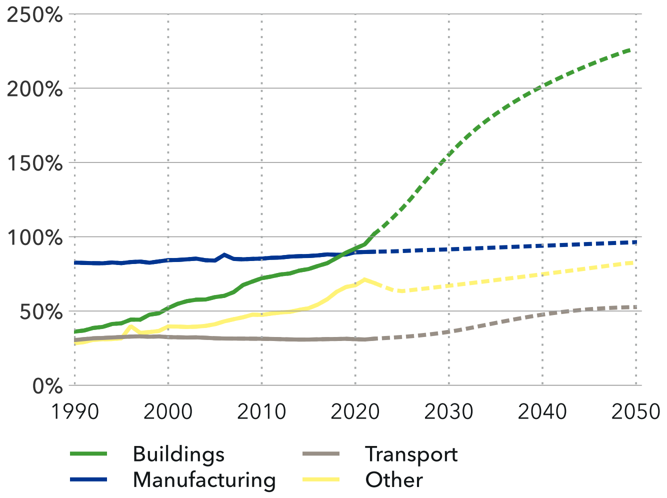
The concept of 'Useful Energy Demand' refers to the efficient conversion of consumed energy into practical forms like motion, heat, and light. Ideally, measuring useful energy would involve tracking energy losses across various systems like boilers, furnaces, engines, motors, and heat pumps. However, due to practical constraints, we often rely on estimated conversion efficiencies to determine the useful energy consumption on a sectoral and national scale. Despite potential inaccuracies in these estimates, analyzing trends in equipment efficiency allows us to discern patterns in sectoral efficiency. For example, Figure 5.21 illustrates these trends across various sectors in China, comparing the ratio of final energy (the energy directly delivered to end-users in forms like oil, gas, electricity, or hydrogen) to useful energy.

In the buildings sector, there has been a significant improvement in efficiency over time. Historically, this improvement was propelled by transitioning from inefficient traditional cooking and heating methods, like biomass stoves and coal, to more efficient systems such as modern gas boilers. As China's population increasingly relocates from rural areas to modern urban apartments, this trend persists. A key factor in the buildings sector's efficiency surpassing other sectors by 2050 – achieving over 200% efficiency – is the widespread adoption of air conditioners and heat pumps. With more households and businesses using air conditioning, space cooling is set to consume a larger portion of energy. Thus, despite the high efficiency of these cooling systems, the overall final energy demand in the buildings sector is expected to rise.

FIGURE 5.21

Final to useful energy efficiency by sector

Units: Percentages



The manufacturing sector exhibits a consistent, albeit gradual, increase in efficiency. This reflects ongoing improvements in manufacturing processes and technologies, which enhance energy utilization. The introduction of heat pumps for low-temperature heat processes also contributes to this. However, the shift towards increased mechanization in industrial processes, which favours electricity-consuming machines over manual labour, somewhat counterbalances these efficiency gains. Therefore, efficiency improvements in the manufacturing sector are projected to be moderate.

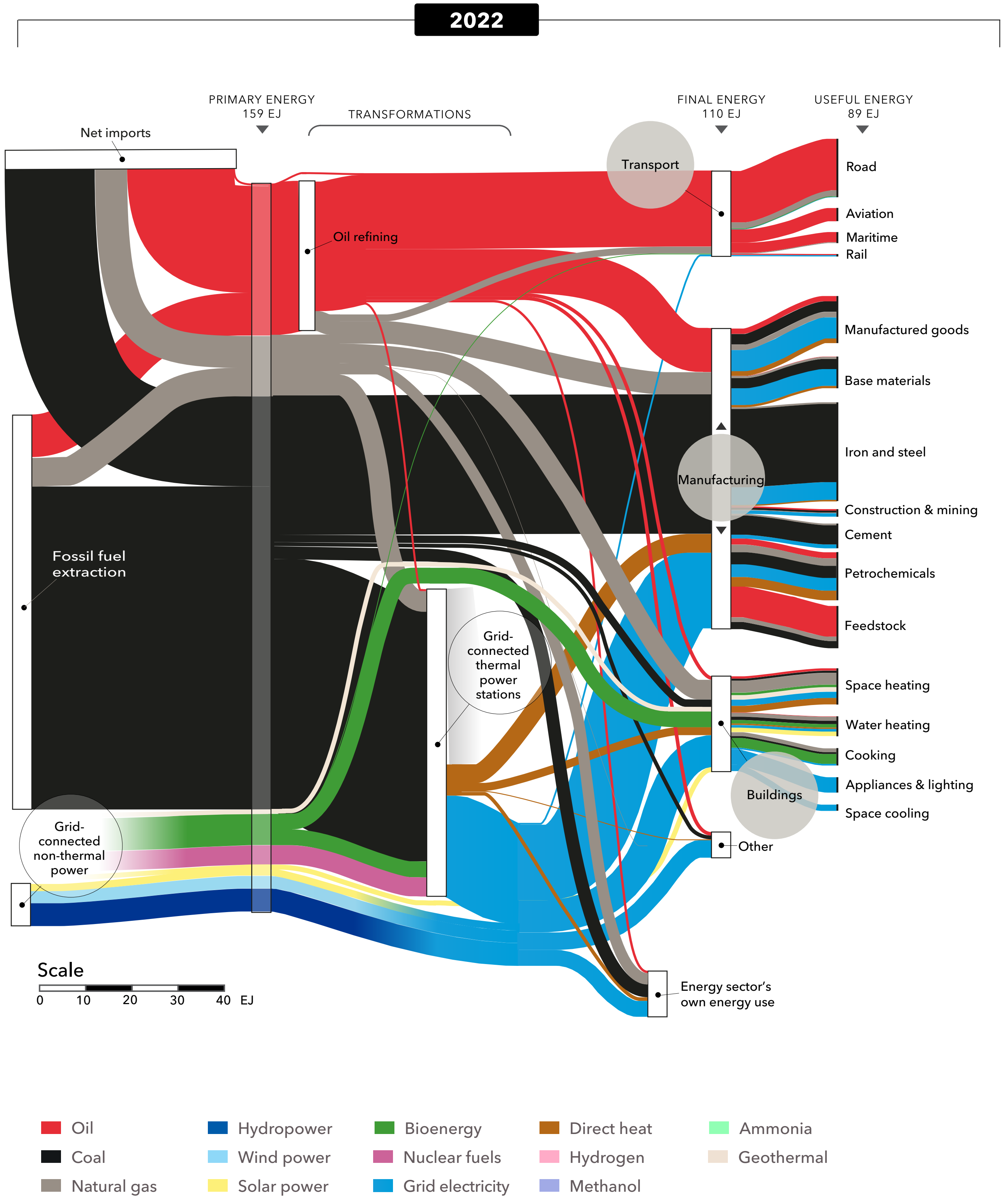
In contrast, the transport sector shows no substantial efficiency improvement from 1980 to the early 2020s. However, a modest increase is anticipated, reaching about 75% efficiency by 2050. This potential improvement could be attributed to the adoption of more efficient electric vehicles and a shift towards less energy-intensive transportation modes, like high-speed rail.

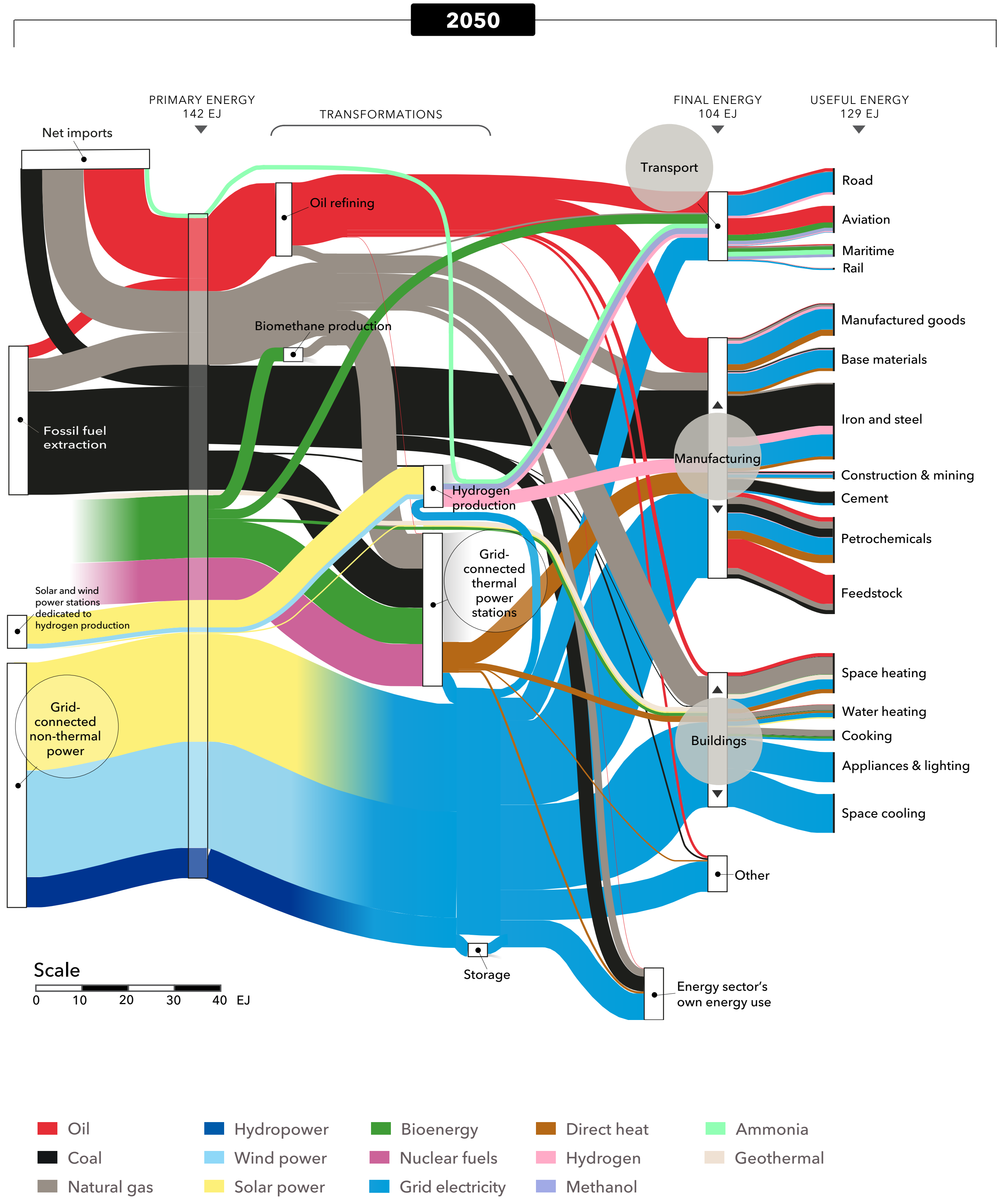
The 'Other' category, which includes sectors like agriculture and fishing, exhibits the least improvement, maintaining around 50% efficiency throughout the period. This stagnation may be due to these sectors' limited potential for efficiency gains or slower adoption of energy-saving technologies.

To complement these trends, China has implemented policies aimed at reducing the demand for energy services. These include insulating buildings to enhance energy efficiency, increasing recycling rates to reduce waste and energy consumption in production processes, and promoting use of public and non-motorized transport to discourage excessive use of fuel-consuming transportation. While these strategies do not directly impact the final-to-useful energy ratio, they play a crucial role in reducing overall energy consumption and, in some cases, eliminating the need for it.

From 2022 to 2050, China's energy intensity will reduce by 51% (from 4.5 to 2.2 MJ/USD).

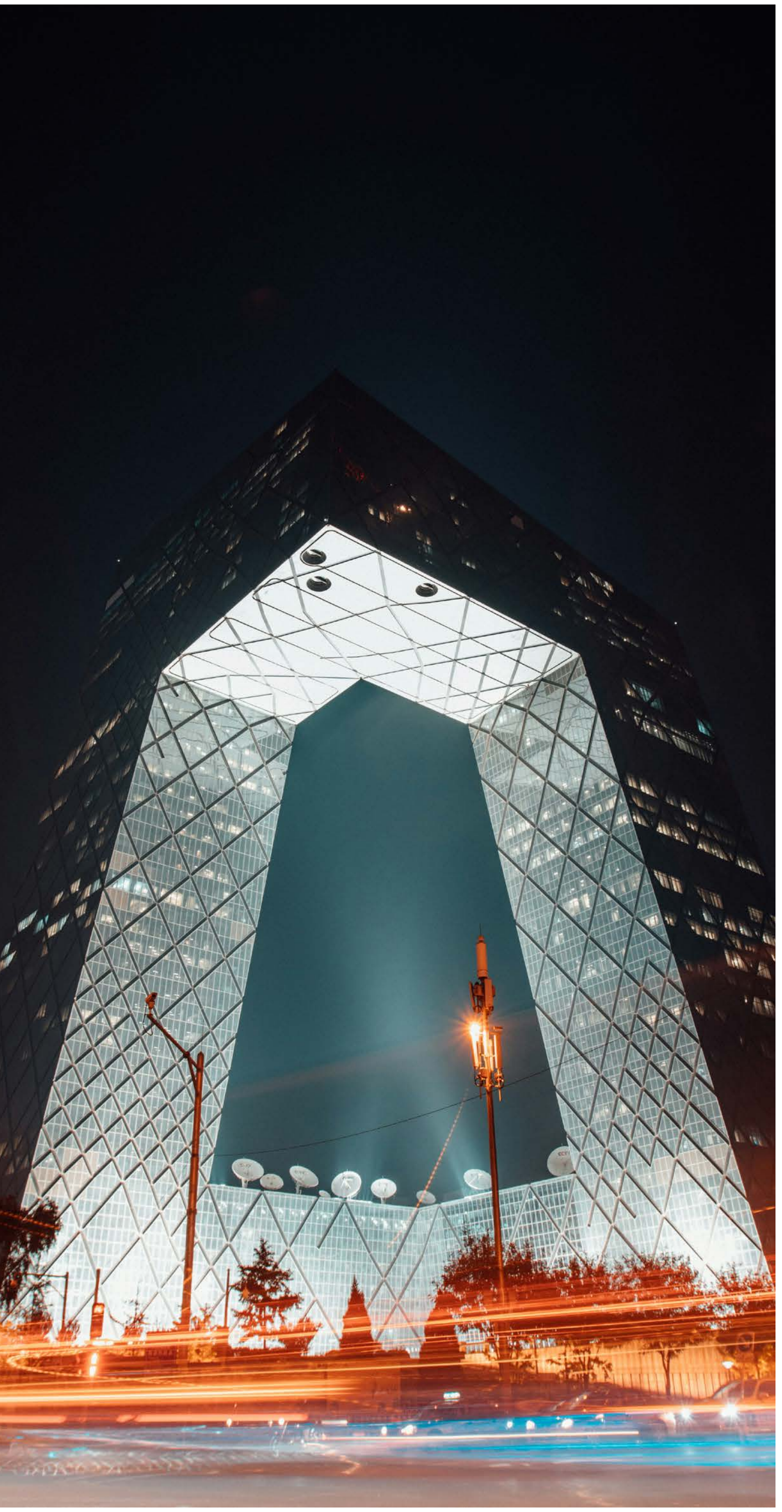
5.9 Comparison of energy flows





6 FINANCE AND INVESTMENTS

China has aggressively invested in its energy infrastructure over the last two decades. We forecast this investment trend will continue in the coming decades, pushed by an ever-increasing need for electricity.



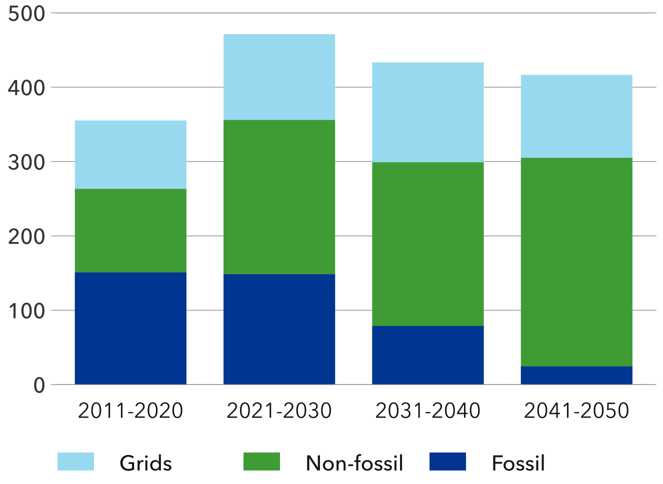
China is investing more than any other country in energy supply and infrastructure. Around 13% of global energy supply investments were made in China in the past decade, and we forecast this share to stay stable over the coming decades. However, Figure 6.1 shows the distribution of these investments will significantly change as fossil-fuel investments are progressively replaced by non-fossil ones. Yearly investments will be at their highest level in this decade, around USD 470bn, before a slight decline in the following two decades.

Self-sufficiency and energy security are an essential part of China's policy, as we discussed in more detail in Chapter 2. Although China is already sourcing a lot of its energy supply domestically, mainly through coal and renewables, it still relies on large imports of oil and natural gas. However, the progressive decline of fossil-fuel use combined with a growing renewable energy uptake will continue to increase the domestic content of energy. This is one reason why investments will stay at a high level even though energy demand will start declining from the 2030s.

FIGURE 6.1

Average yearly energy supply investments

Units: USD billion/yr



Favourable financing conditions

These huge investments, both past and future, are supported by favourable financing conditions compared to the rest of the world, especially for clean energy (DNV, 2023b). The *Opinions on Financial Support for Carbon Peaking and Carbon Neutrality* issued by China's Ministry of Finance (MOF, 2022a,b) indicate that transition support will continue (see Chapter 2 for more details). One notable feature is the generally lower cost of capital (CoC) in China, which is one of the key cost drivers for capital-intensive projects like new power generation, power grids, and gas infrastructures, and for end-use subsectors such as buildings, equipment, and zero-emission vehicles.

Our forecast uses the levelized cost to compare competing technologies, where the ratio of lifetime costs to lifetime generation (like electricity or hydrogen production) are discounted back to a common year using a discount rate that reflects the cost of capital.

With higher discount rates, the break-even price that satisfies equity and debt returns moves up. Hence, predicting the competitiveness of, for example, competing power generation technologies now and in the future requires carefully weighed CoC predictions. It is a crucial parameter in our forecast to 2050 and DNV has therefore continued focus on the granularity of the CoC.

In China, state-owned entities provide the bulk of equity and debt, with low return requirements and subsidized interest rates keeping CoC down. Figure 6.2 shows the future CoC assumed in our forecast. The picture will be different for fossil and non-fossil sources.

For fossil sources, as in other growing economies in low- and middle-income countries, we expect China to continue to finance new coal investments at competitive rates through the 2030s, after which we expect a rapid increase in risk and therefore CoC. The rise in CoC is driven by the central government announcing its intention to limit the increase in coal consumption over the *14th Five-year plan* period and to phase down coal during the *15th Five-year plan* period, suggesting reduced availability of capital and falling demand for coal. For non-fossil sources, we expect both renewables and nuclear to have access to stable and competitive financing throughout the forecasting period.

Coal production investments to remain at high levels

Coal has been and is still at the centre of China's energy system. China is currently the largest producer and consumer of coal, covering over 90% of its demand with domestic supply (Nakhle, 2023). However, the time for massive investments in production is now over. As shown in Figure 6.3, as coal production gradually declines, so will investments. Just around USD 60bn will be necessary through 2050 to keep production at sufficient levels.

Although China is far from energy independence for oil and gas, China is also a significant producer of these fossil fuels (see Chapter 5). This means that investments will continue, especially in this decade when they will be above USD 1trn. Gas will then dominate the investments from the 2030s on.

FIGURE 6.2

Development of cost of capital

Units: Percentages

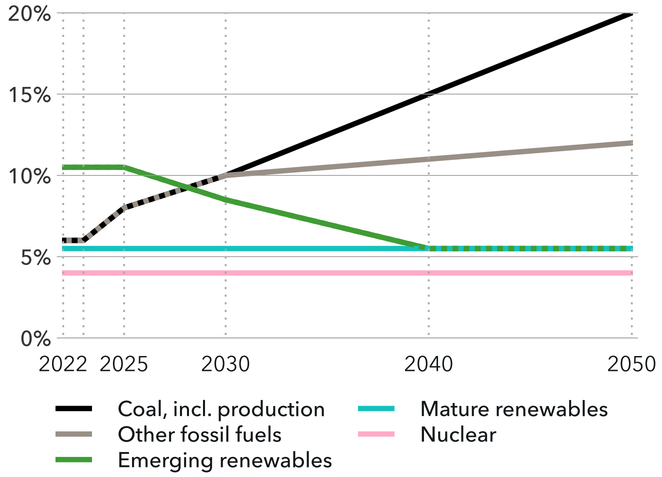
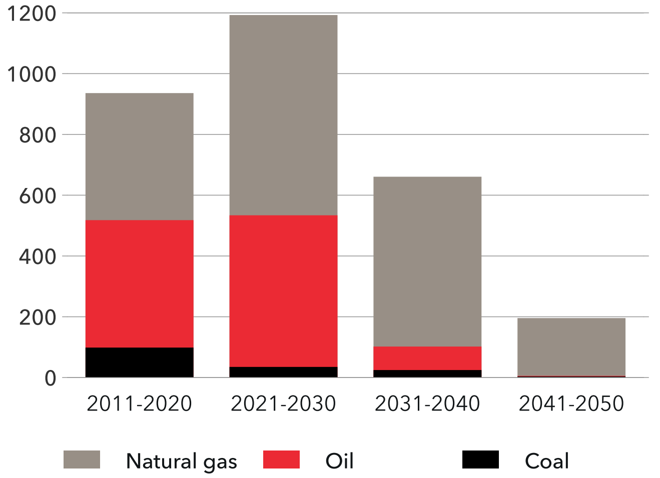
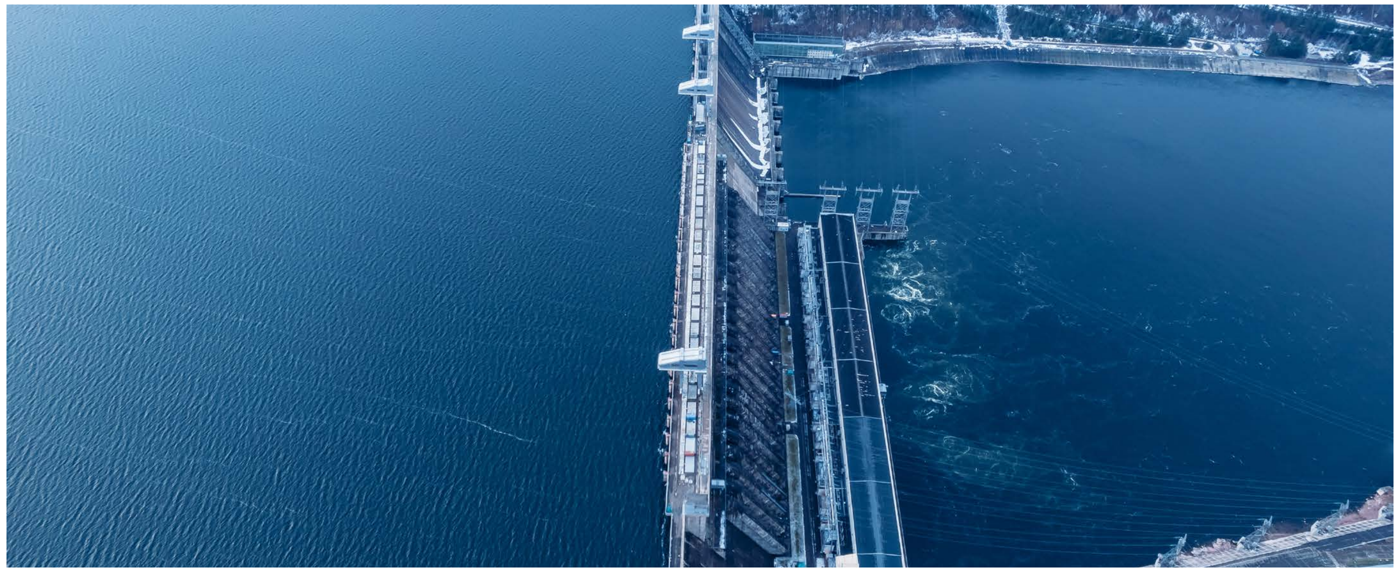


FIGURE 6.3

Cumulative upstream fossil fuel investments per decade

Units: USD billion





Non-fossil generation set to dominate power investments

Power generation will account for most of the investments in the energy sector, as electricity is set to double its share to cover about half of energy demand by 2050. As shown in Figure 6.4, the forecast transition will result in a shift from relatively modest investments to CAPEX-intensive non-fossil power generation, driving up investments in these asset classes over the next decades.

Investments in renewables will be over USD 150bn annually before 2030 and reach around USD 250bn per year by 2050. On the global scale, China will account for 35% of global investments made in solar PV until 2030, 27% of wind, and 40% of nuclear, totalling about USD 1.3trn in these three sectors only.

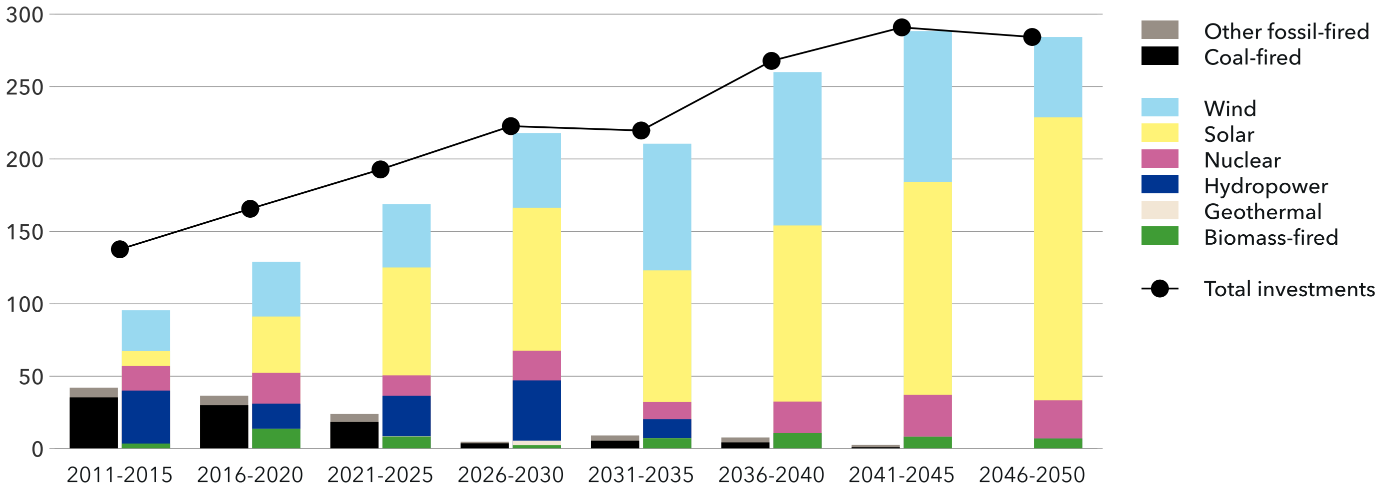
With the world's largest potential, hydropower has been an early target for power investments in China. Over USD 330bn will be invested for an additional 120 GW during the coming decade, until reaching the maximum potential of hydropower of around 500 GW, limited by natural hydrological constraints, in the mid-2030s.

Although much lower in absolute terms, China will still represent a third of global coal investments over the same time period. These lower investments do not mean that total expenditures (including operational costs) in fossil-fired power will be low. The long lifetime of coal-fired power plants, some of them even still being built, means that operational costs, and especially fuel costs, will continue to dominate power sector expenditures. It is only in the early 2040s that yearly non-fossil power expenditures will be higher than their more expensive fossil counterparts.

FIGURE 6.4

Average yearly investments in power generation

Units: Billion USD/yr



Power grids investments to support capacity additions

Electrification will drive investments in power grids that will stay well above USD 1trn per decade during our forecast period, as shown in Figure 6.5. Increased electricity demand in the buildings and road transport sectors means that investments in the distribution network will need to increase through 2040 to allow access for the end-users.

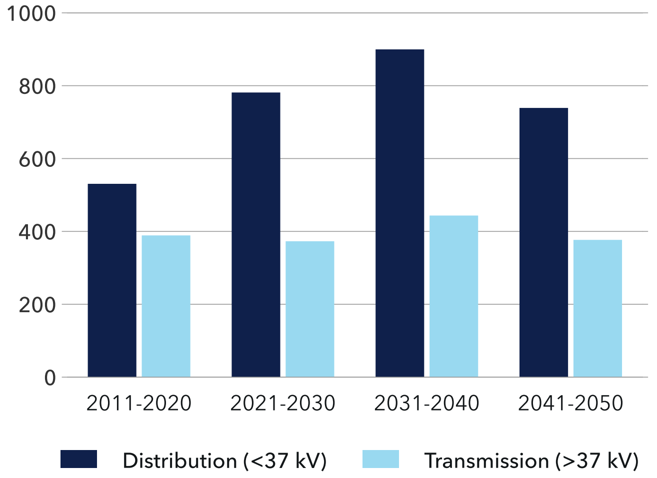
For transmission powerlines, the forecasted tripling of installed capacity by 2050 – with 90% of the new capacity coming from variable wind and solar and the electrification of the manufacturing sector – means that significant investments are also necessary. This is in line with the *14th Five-year plan* (Government of China, 2021) that emphasizes strengthening and deployment of high- and ultra-high- voltage transmission channels to connect clean energy bases with consumption centres.

Investments in grid-connected 'new energy storage' are also growing quickly. Since the *14th Five-year plan*, the new installed capacity of new energy storage is estimated to have directly promoted economic investment of more than CNY 100bn (USD 14bn) and has become a 'new driving force' for China's economic development (Government of China, 2024). We forecast these investments will increase rapidly as unit costs decrease and grid-balancing needs increase (see details in Chapter 4).

FIGURE 6.5

Cumulative power grids investments by decade

Units: USD billion



Beyond the energy infrastructure

The development of energy infrastructures in China is backed by huge upstream investments in manufacturing, mining, and research. Although not directly modelled in our forecast, these are essential for understanding China's energy transition context.

Indeed, the favourable cost of capital mentioned earlier is not only reflected in the installation of energy assets, but also along the whole supply chain. This, together with significant government support – ranging from state-directed R&D to investment funding and fiscal incentives – helps keep the price of Chinese-made renewable technology competitive at a global level and is one of the key reasons behind the domination of China in clean energy manufacturing (see Section 3.3, Manufacturing).

Overall, clean energy sectors (including solar power, EVs, and batteries) are currently driving growth in China. With investments totalling USD 890bn in 2023 and growing 40% year-on-year, they almost equalled all global investments in fossil fuel supply the same year (Myllyvirta, 2024). This trend will continue as China's *2024 Catalogue for Guiding Industry Restructuring*, a government roadmap for investment, puts clean energy technology as one of the top priorities (NDRC, 2024).

Emerging renewables technologies, like electrolysers for green hydrogen production, also have access to easier financing than in other regions. China is already leading in this growing sector, with around half of global investments in the 2020 to 2022 period (IEA, 2023a). This supports the forecasted growth of hydrogen from electrolysis, with China representing about a third of global production by 2050.

Mining for critical minerals also attracted investments in the past years, with increased spending from companies specializing in lithium, copper, and nickel development up as much as 50% year-on-year (IEA, 2023a).

All these developments are supported by strong investments in R&D providing technologies and skilled workforce to the industry. China is the largest public spender on energy research, with a recent average of USD 4bn to 6bn annually. The *14th Five-year plan* is cementing that position by aiming to increase energy R&D spending by 7% annually (OIES, 2022).

Overseas investments

China is also investing in energy infrastructure abroad. Primarily through the *Belt and Road Initiative*, for which the energy sector accounted for most investments and construction deals signed since its inception. Originally dominated by coal-fired power plants, the investments are now turning to wind and solar, which represented the largest share of investments in the first half of 2023. This boost in exports also helps alleviate the overcapacity issue in these industries (Baxter, 2023).

China's ambitious energy security targets cannot be assured by domestic supply alone, as China is lacking some key natural resources (e.g. oil and some critical minerals). For this reason, China is extensively investing abroad to secure its supply. China is now changing its financing strategy, replacing loans with more direct investments, with the resource-rich African continent being a prime target (Mitchell, 2023).

Coming investments for carbon capture and storage

As detailed in Chapter 7, carbon capture and storage (CCS) became part of China's decarbonization strategy with its incorporation in the *14th Five-year plan*. Investments shown in Figure 6.6 will progressively increase from the second part of this decade and will be mainly directed towards ammonia and methanol production. They will total over USD 100bn, or 20% of global investments in CCS, by 2050.

Stable residential expenditures

The massive investments described in this chapter are conducted by the government, SOEs, and private enterprises (see Section 2.1). However, it is also important to understand what the energy transition entails for the individuals in China. The acceptability of the energy transition is a relevant indicator of its success, and household energy expenditures will have a decisive impact on whether the transition is considered socially acceptable.

Figure 6.7 presents residential energy expenditure per capita. Residential energy expenditure includes CAPEX for residential space heating and cooling, water heating (such as the cost of heat pumps), cooking (such as the cost of electric stoves), and OPEX, which is the energy costs and energy taxes of running all the household equipment, along with passenger vehicles.

In 2022, the average residential energy expenditure was about USD 600 per person-year in our analysis, representing around 10% of the average disposable income (NBSC, 2023). While disposable income is likely to significantly increase in line with GDP, residential energy expenditures are forecast to remain stable to 2040 before a later growth.

This stability also contrasts with two factors increasing energy consumption: the forecast decline in household size (which is associated with more living space per capita) and the increasing access to individual cars. This shows the positive influence of electrification, with electricity being overall more affordable for buildings and individual transport.

FIGURE 6.6

Cumulative investments in carbon capture and storage

Units: USD billion

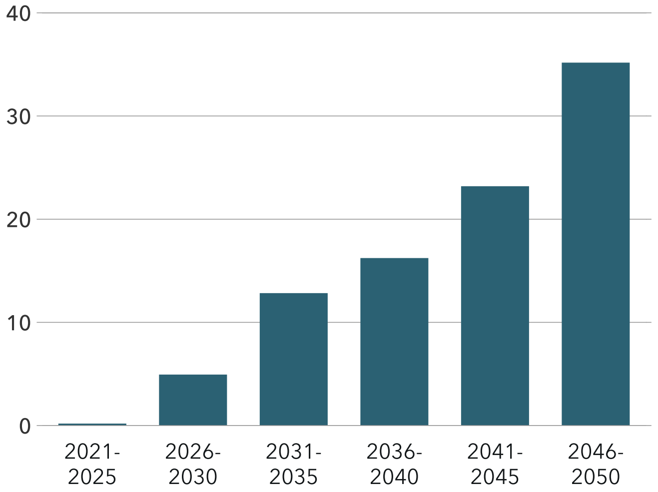
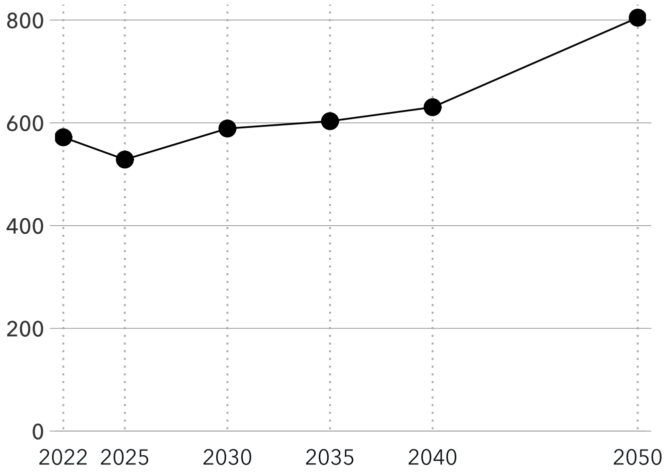


FIGURE 6.7

Residential energy expenditure per capita

Units: USD/year



7 CARBON EMISSIONS AND REMOVAL

China uses 57% of the world's coal and emits 32% of energy-related CO_2. There is increasing pressure from other countries for China to reduce its emissions faster. From the Chinese authorities' point of view, a balance is important; emissions reduction are only one of several priorities. Stability in energy prices, energy security, and economic goals are overriding objectives in Chinese policies.

7.1 Energy and process-related CO_2 emissions in China

China's most pronounced climate policy is its commitment for CO_2 emissions to peak before 2030, and to reach climate neutrality in 2060. On the 2030 goal, there is an array of supporting targets, goals, and measures, both in the present *14th Five-year plan to 2025* and the *15th Five-year plan to 2030*. On the 2060 goals, there are very few supporting measures so far.

The national emissions trading scheme will cover high-emission sectors (70% of emissions) with sectoral expansion happening gradually to 2030, pressured by the EU's carbon border adjustment mechanism (CBAM).

We estimate China's average carbon-price level to be USD 20/tCO_2 in 2030, USD 40/tCO_2 in 2040, and increase to USD 90/tCO_2 by 2050, a level exceeded only by Europe and the OECD Pacific regions. The upward pricing trend is underpinned by the inclusion of more sectors and expanding coverage in China's national emissions trading scheme (see Section 2.2).

China's high-level goal of carbon neutrality by 2060 cannot be identified in our forecast, which stops in 2050. Energy and process-related CO_2 emissions after carbon capture and storage (CCS) – and net of direct air capture (DAC) – are expected to have decreased 66% compared with 2022 levels, with 4.2 $GtCO_2$/yr remaining in 2050. The direction in 2050 is clear, but the present trajectory makes it unlikely that full carbon neutrality will be achieved by 2060 unless China changes course to decarbonize, and specifically de-coal, its economy even more rapidly. China aims to reduce carbon intensity (per unit of GDP) by 65% from 2005 levels by 2030; we forecast a reduction of only 59% by then.

Energy and process-related CO_2 emissions

In 2022, 33% of global energy and process-related CO_2 emissions – 22% from coal, 7% from other fuels and 4% process emissions – were from China. This share has increased steadily, with the highest growth (from 14% to 27%) being in the period from 2000 to 2010. By the mid-2030s, China's emissions will fall much more rapidly than the global average, with China accounting for 22% of global energy and process-related CO_2 emissions in 2050. In absolute terms, China's emissions, shown in Figure 7.1, are the biggest in the world, at around 12.1 $GtCO_2$ of energy and process-related emission in 2022, a new record high. China's coal use increased steeply until 2013 and has since hovered around that year's level. Coal consumption increased between 2021 and 2022 and soared further in 2023. We project that consumption will plateau for the next four to five years before gradually reducing to a third of its current level by 2050. The decline is due to the power generation transition from coal to renewables, which starts to make a real impact by 2035. The power sector's share in energy and process-related emissions had the biggest share in 2022, but reduces from the current 44% to 23% in 2050, with an absolute reduction from 5.4 $GtCO_2$/yr to 1 $GtCO_2$/yr.

Manufacturing's sectoral share of energy and process-related CO_2 emissions in 2022 was the second largest among the main energy demand sectors (4.3 $GtCO_2$/yr). The share increases from 35% today to 49% in 2050, albeit while halving in absolute terms. The main reason is similar to the power sector: the decline in the use of coal.

China's transport sector emissions have grown in line with growing transport demand. Road transport demand represents almost 70% of those emissions but is also set to decline the fastest. In 2022, CO_2 emissions from transport were 1.3 $GtCO_2$/yr and they are set to peak by the middle of this decade at 1.4 $GtCO_2$/yr. Emissions from road transport will rapidly decline, while emissions from maritime transport will take another five years to start declining. Aviation is by far the slowest of the transport sectors' emissions to decline. This is due to the increasing demand for flying, combined with a lack of easy or cheap decarbonization technologies. By 2035, it seems that emissions from aviation will peak and by 2050 the emissions will be down to slightly higher than the levels of 2022, about 20% lower than the peak.

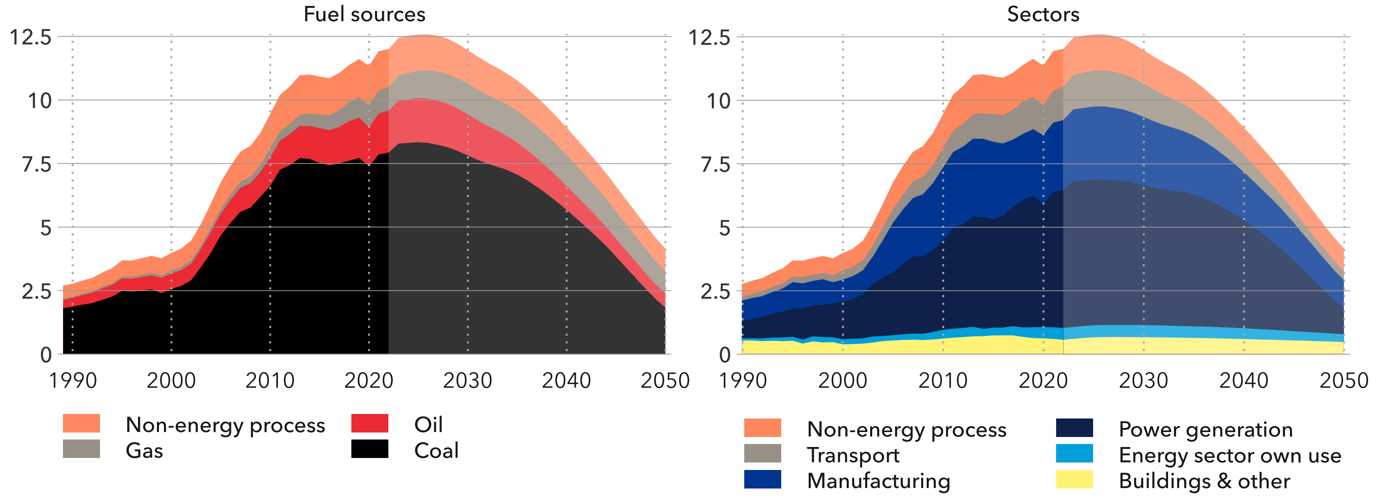
The emissions from the China's building sector stay almost the same as today (0.42 $GtCO_2$/yr), which was around 4% of total energy and process-related CO_2 emissions in 2022, but will represent 10% of China's emissions in 2050. However, the fuel mix changes significantly, where today 35% of the emissions come from coal, 10% from oil, and the rest is based on natural gas. By 2050, 82% of emissions will be from natural gas, 10% from coal, and the rest from oil. This change happens while energy demand from the buildings sector will increase by 40% and total floor area space grows by 50%.

> China aims to reduce carbon intensity (per unit of GDP) by 65% from 2005 levels by 2030; we forecast a reduction of only 59% by then.

FIGURE 7.1

Energy and process-related CO_2 emissions by fuel source and sector

Units: $GtCO_2$/yr



7.2 Carbon removal, CCS, and DAC

Carbon capture and removal encompasses a suite of technologies that can help reduce CO_2 emissions from sectors that continue to use fossil fuels. Carbon capture refers to the separating and capturing of CO_2 from sources with high concentrations, such as in flue gases of fossil-fuelled power stations and heavy industries (e.g. cement or petrochemicals). Carbon removal refers to the process of removing CO_2 in low concentrations from the atmosphere. In both cases, the captured or removed CO_2 can be either utilized for producing value-added products (such as e-fuels or fizzy drinks) or transported and stored in geological or marine reservoirs. Thus CCS is a method of countering and reducing industrial emissions, whereas DAC and storage is a negative emission technology. CCS combined with further utilization of captured CO_2 is referred to as CCUS (U for utilization).

China's deployment of CCS capacity has been lagging behind other regions, such as North America and Europe. Large-scale commercial facilities have emerged only as the most recent development. In August 2022, China launched its first integrated megatonne-scale CCUS project, Qilu Petrochemical – Shengli Oilfield, located in Shandong province (Sinopec, 2023). Another large-scale, 1.5 Mtpa, Huaneng CCUS project in coal-fired power began construction in December 2022 in Gansu province. Furthermore, Shaanxi Yanchang Petroleum announced plans to build a 5 Mtpa-scale CCUS facility (GCCSI, 2023a).

There has also been a parallel shift in the policy support for the technology. CCS has been included in the key policy documents within China's `1+N` climate framework, which provides guidance for the country's efforts to achieve its dual carbon goals, as well as in the decarbonization strategies of some of the provincial governments. For the first time, CCUS has been incorporated into China's *14th Five-year plan (2021-2025)* among key environmental protection and resource conservation projects. There is a shift towards mentioning CCUS beyond power and oil and gas industries and towards more sectoral policies, such as hard-to-abate industries (GCCSI, 2023b). This indicates that CCS is expected to play a crucial role in achieving carbon neutrality in China. However, these developments should be viewed more as policy signals with the concrete policy tools yet to be established. Such policy tools are essential since the cost of CCS in most of application processes is still prohibitively high which means the technology cannot be driven only by economic considerations.

At the moment, the scale of CCS in China is immaterial, with 11 projects in operation accounting altogether for only about 1 out of 26 $MtCO_2$ captured per year globally. However, given four more CCS facilities in development, six in construction, and around 100 projects of various scale in demonstration, we expect a steady increase in CCS starting the end of the 2020s. The capture rates are forecasted to reach 38 $MtCO_2$/yr in 2030, 148 $MtCO_2$/yr in 2040, and 277 $MtCO_2$/yr in 2050 (Figure 7.2).

Currently, 61% of emissions captured come from natural gas processing, where the cost of capture from high-pressure streams is one of the lowest. However, due to a scale-up of other CCS applications, this share will drop to 4% already in 2028 and continue declining, further leading to nearly zero emissions captured from this source by 2050. Initially, CCS will be driven largely by capturing process emissions, namely in ammonia and e-fuel production, owing to relatively lower costs of capture for these applications. Combined ammonia and e-fuel production will make up 78% of all emissions captured in 2030 and sustain this share through 2040. Starting early 2040s, the increases in capture applications in electricity generation and manufacturing (iron and steel) will be driving most of the growth in CCS, comprising 23% and 14% of all captured emissions by the mid-century.

The explanation for the shift in driving forces of CCS deployment in the later part of our forecast period is dual. First, some level of capacity deployment for these applications in prior periods will reduce initially high costs of capture to some extent because of technological learning. Second, China's *Blue Book on the Development of New Power Systems* envisions CCUS uptake during a later period between 2030 and 2045. Given a relatively young coal power fleet and ongoing coal capacity additions in China (we forecast that about 5% of electricity generation will still come from fossil energy in the mid-century), as well as limits to decarbonizing hard-to-abate manufacturing processes, these applications will likely be key targets for further expansion of CCS in the 2040s. The share of process emissions application will still be significant but constitute only 54%.

Currently, China has only started research and development of CO_2 removal technologies such as DAC: in particular, high-performance adsorbent and absorption material preparation (GCCSI, 2023b). We expect China to continue building on these efforts and deploy DAC for the removal of some of its emissions, although not at a large scale. By 2050, only about 2 $MtCO_2$/yr will be removed using DAC, which is substantially lower than the levels that we expect to be achieved in, for example, North America, Europe, and Asia Pacific.

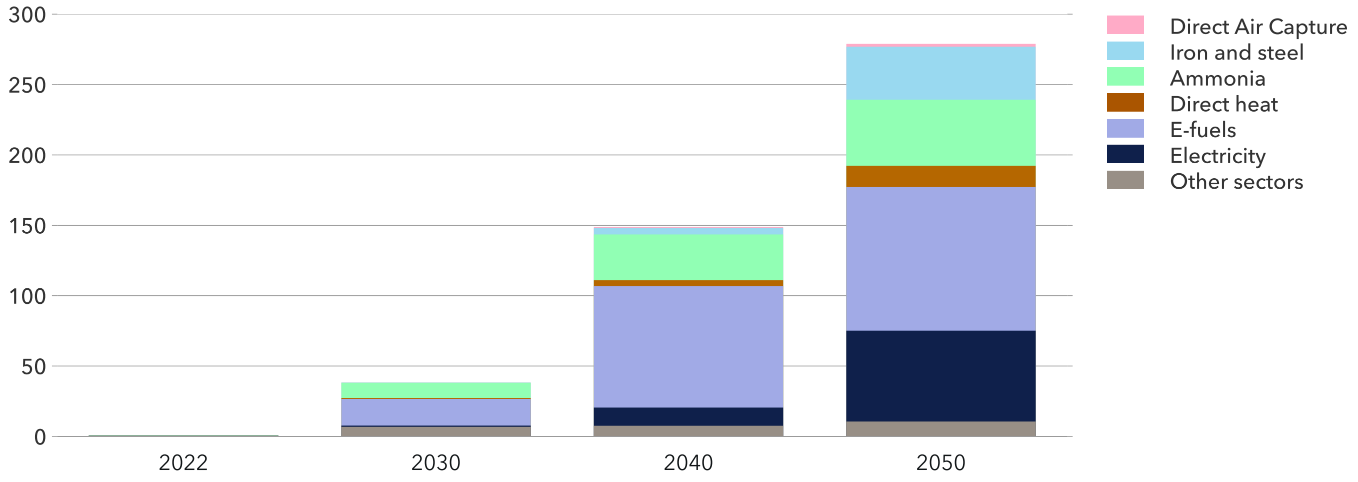
Altogether, we forecast only 9% of emissions in China to be captured by CCS or removed by DAC in 2050. This demonstrates that to achieve its carbon neutrality goal, China needs to consider substantially enhancing its support for CCS and DAC. In practice, this would mean moving from policy aspirations and signals to concrete policy mechanisms, such as incentives and regulatory measures, as well as the development of effective business models.

CCS and DAC combined will only be capturing 9% of emissions in China in 2050.

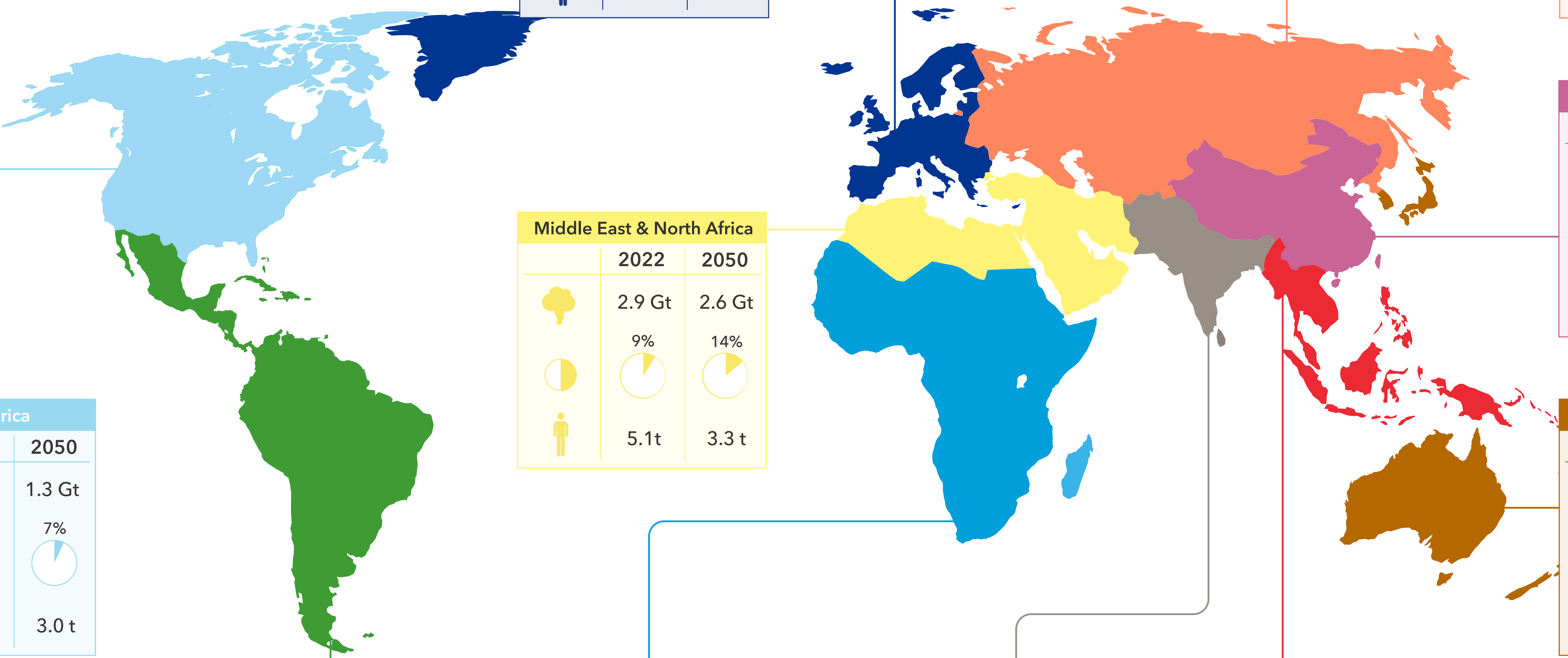
FIGURE 7.2

CO_2 emissions captured

Units: $MtCO_2$/yr



ENERGY RELATED EMISSIONS*



Europe

	2022	2050
☁	3.1 Gt	0.5 Gt
◐	9%	2%
🚶	5.6 t	0.8 t

North East Eurasia

	2022	2050
☁	2.4 Gt	1.7 Gt
◐	7%	9%
🚶	7.6 t	5.0 t

China

	2022	2050
☁	10.5 Gt	3.3 Gt
◐	32%	20%
🚶	7.4 t	3.0 t

Middle East & North Africa

	2022	2050
☁	2.9 Gt	2.6 Gt
◐	9%	14%
🚶	5.1t	3.3 t

North America

	2022	2050
☁	5.2 Gt	1.3 Gt
◐	16%	7%
🚶	13.8 t	3.0 t

OECD Pacific

	2022	2050
☁	2.0 Gt	0.4 Gt
◐	6%	2%
🚶	9.5 t	2.0 t

Latin America

	2022	2050
☁	1.5 Gt	1.1 Gt
◐	5%	6%
🚶	2.3 t	1.5 t

Sub-Saharan Africa

	2022	2050
☁	1.0 Gt	1.3 Gt
◐	3%	7%
🚶	0.8 t	0.6 t

Indian Subcontinent

	2022	2050
☁	3.0 Gt	3.9 Gt
◐	9%	22%
🚶	1.6 t	1.7 t

South East Asia

	2022	2050
☁	1.7 Gt	1.4 Gt
◐	5%	8%
🚶	2.5 t	1.8 t

☁ Total energy-related CO_2 emissions

◐ Share of world emissions

🚶 Energy-related per capita emissions

*process-related emissions are not included in this graph/map

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Historical data

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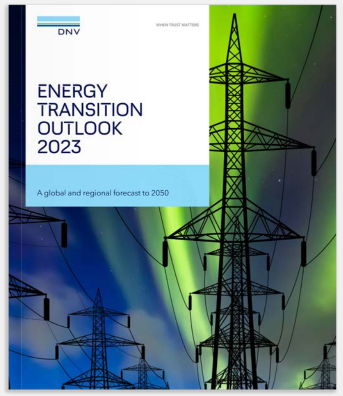

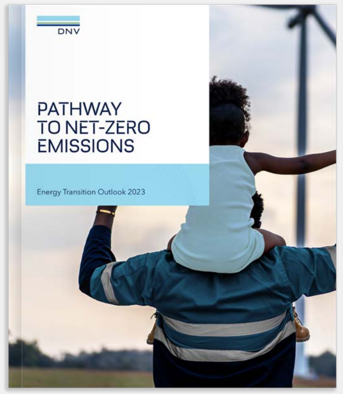

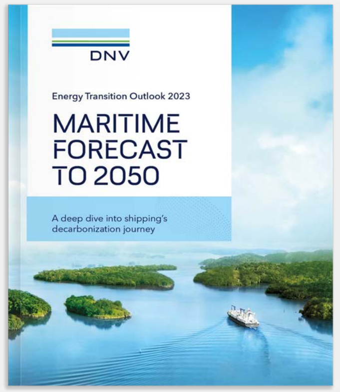

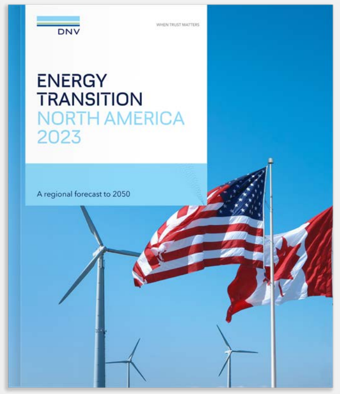

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