Shell Scenarios Sketch

ACHIEVING A CARBON-NEUTRAL ENERGY SYSTEM IN CHINA BY 2060

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LENSES ON ENERGY TRANSITIONS
REGIONAL AND COUNTRY


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FOREWORD
BY JASON WONG

Climate change is one of the biggest challenges faced by modern humanity, and China has an integral and critical role to play in tackling it.

What you read in this scenario sketch is an invitation to look far into the future of China's energy system. It sets out a potential pathway for China to achieve net-zero CO_2 emissions from the production and use of energy by 2060.

As the world's largest energy consumer and carbon emitter, the top producer of renewable energy as well as the leader in electric vehicle manufacturing and adoption, China is an important part of the global climate challenge and solution. President Xi Jinping's pledge in 2020 that China would aim to achieve peak emissions before 2030 and carbon neutrality by 2060 (the 3060 targets) is a defining moment in the global decarbonisation journey towards a more sustainable future.

> "...clear long-term goals and policy road maps are positioning China at the forefront of the low-carbon industrial revolution..."

China, which contributed 27% of global emissions in 2019[1] will need to reduce its carbon emissions at a pace faster than any country in history[2] to reach its 3060 targets.

The country is already making progress towards achieving the largest energy system transformation in the world. Its clear long-term goals and policy road maps are positioning China at the forefront of the low-carbon industrial revolution, while ensuring sufficient and growing energy supply to power its economic expansion in coming years.

As China shifts away from a reliance on coal, towards renewable and clean energy sources, it can benefit from significant opportunities arising from the development of low- and no-carbon energy sources and technologies as well as new growth industries. It's pathbreaking green revolution offers the potential for far-reaching positive impact at an industrial, economic and social level, both at home and across the world.

The scale and significance of this energy transition explains why the ways to achieve the 3060 targets are hotly discussed. This scenario

sketch sets out a deep and rapid decarbonisation pathway for China to achieve these goals in time. Our view, that it is economically and technically possible for China to do so, is informed by deep analysis, as well as our experience and long history of serving China's energy needs.

For 128 years – and counting – we have built deep roots here: forging trusted relationships with our Chinese partners and customers, while contributing to energy research in collaboration with central government bodies such as the Development Research Center of the State Council.

Shell's Powering Progress strategy – to be a net-zero emissions energy business by 2050, in step with society – positions us well to provide the clean, sustainable energy solutions that China needs to fulfil its net-zero emissions pledge and vision of an ecological civilisation. From natural gas to renewable energy, consulting projects on energy efficiency and low-carbon technology solutions, our products and services support companies and governments as they reduce carbon emissions, sector by sector. These include sectors that are difficult to decarbonise, such as heavy industry and aviation.

Achieving the 3060 targets will be a tough battle, as President Xi has acknowledged. He also made it clear that China is able and committed to achieving both high-quality growth and environmental protection, which he likened to "green mountains and clear waters" that are as valuable as "mountains of gold and silver". We are in this battle together and we are going to win it together!

One of my favourite Chinese idioms is "stand high and look far" (高瞻远瞩). That is exactly what this scenario sketch sets out to do. It aims high to provide a platform for all stakeholders to hold far-sighted discussions to forge coalitions and shape policy frameworks.

On this unprecedented journey towards net zero, it is crucial we all stand high, look far and take solid steps.

Jason Wong
Executive Chairman,
Shell Companies in China

> Make no mistake, achieving the 3060 goal will not be easy. It calls for fundamental changes to the Chinese energy system at a pace of change that will be highly challenging.

INTRODUCTION

TOWARDS AN ECOLOGICAL CIVILISATION

The transition to a lower-carbon energy system in China has been gathering significant momentum.

In 2015, President Xi Jinping addressed the opening ceremony of the Paris climate conference, declaring climate change "a shared mission for all mankind". In the same year, China pledged to achieve peak carbon dioxide emissions around 2030 and promised to lower CO_2 emissions per unit of GDP by between 60% and 65% from 2005 levels.

The Chinese Communist Party raised another milestone in the country's new era for socialism with Chinese characteristics during its 19th National Congress in 2017. It announced a clear environmental focus on "energy conservation and environmental protection" policies and on "contributing to global ecological safety". By 2018 the concept of "ecological civilisation" had been written into the Chinese constitution.

In September 2020, these objectives were strengthened with the 3060 targets: aiming for a peak in carbon emissions before 2030 and carbon neutrality by 2060.

Building on Shell's analyses and insights, this sketch sets out a potential pathway for China to achieve net-zero CO_2 emissions from its energy system by 2060. Variations of this pathway are possible, depending on societal and policy preferences for particular technologies and fuels, but the fundamental principles are clear.

The sketch builds on Shell's **Sky 1.5** scenario[3], which is consistent with the stretch goal of the Paris Agreement to keep the rise in average global temperature as close as possible to 1.5 degrees Celsius above pre-industrial levels. In Shell's latest **Sky 1.5** scenario, the world achieves net-zero emissions before 2060, with advanced economies reaching that goal earlier. Similar to **Sky 1.5** this scenario sketch is also normative. We have assumed in developing this scenario, that China's energy system reaches net-zero CO_2 by 2060.

At the most recent 26th Conference of Parties (COP26) in Glasgow, 197 countries agreed to the Glasgow Climate Pact to keep alive the stretch 1.5 degrees Celsius temperature stabilisation goal of the Paris Agreement. For the first time, the conference agreed to phase down the use of coal, the most carbon-intensive energy source. China and the USA also reached a bilateral agreement to strengthen cooperation to accelerate action towards the goals of the Paris Agreement.

Make no mistake, achieving the 3060 goal will not be easy. It calls for fundamental changes to the Chinese energy system at a pace of change that will be highly challenging.

However, given the progress made to-date and the changes achieved in just the last decade, we believe it is economically and technically

possible. This transformation will require cross-sector industry coalitions, with a clear mission to reduce emissions and accelerate the pace of change. Crucially, it will take policy frameworks to align interests and sustained commitment from government, business and society more broadly to make progress.

China's determination, scientific expertise and the systematic long-term policy governance of its five-year plans make it uniquely placed to deliver the energy transition.

By setting out a clear, long-term objective to tackle climate change, President Xi's announcements reflect the top priority China places on improving societal and environmental outcomes, alongside delivering economic growth.

CHINA'S ENERGY CHALLENGES TODAY

China is the world's biggest user of energy – with a 21% share of global energy consumption in 2019 – as well as the largest consumer of coal. Most of China's primary energy demand today – almost 60% – is met by coal.

The large size of China's energy system and its reliance on coal means that it also accounts for a significantly larger share of global greenhouse gas emissions (GHG). This reached 24% of the world's total in 2018[4], which was twice the share of the USA – the second-largest emitter with 12% – and more than three times that of the European Union's 7%.

On a per capita basis, China's GHG emissions have only just reached average levels of developed nations. China's large 1.4 billion population meant that its emissions per capita were about 8.2 tonnes of CO_2 in 2018. This was less than half the levels of the USA and Canada in 2018, which stood at 17 tonnes per capita, and higher than the EU 6.5 tonnes per capita.

However, China's per capita emissions jumped to 10.1 tonnes in 2019, and could exceed average Organisation for Economic Co-operation and Development (OECD) levels in 2020.[5] Energy demand growth will persist in the coming decades – and emissions per capita may grow as well – as China's economy continues to expand to attain OECD levels of development and comparable standards of living.

The sheer scale of China's energy system makes it a critical factor in enabling the world to achieve the goals of the Paris Agreement on climate change. If China were to meet its stated climate goals for 2030 and 2060, this could lower the global average temperature rise by almost 0.2 degrees Celsius by the end of the century compared to the baseline, according to the International Energy

Agency's Stated Policies Scenario.[6] In turn, achieving the goals of the Paris Agreement will help China – and the world – to avoid the worst impacts of climate change.

The challenge, particularly in this decade, will be to reduce China's reliance on coal, even as energy needs rise, to support an increase in economic development. China is still in its industrialisation stage of development, with heavy industries such as cement, steel and chemicals accounting for a significant share of economic output.

Much of this industrial capacity is relatively new and reliant on coal. It will require significant investments to switch to lower-carbon production processes, technologies and fuels if China is to achieve its decarbonisation objectives, while avoiding costly early retirement of these industrial assets.

THE IMPACT OF COVID-19

The pandemic has created worldwide disruption, taking a heavy toll on human health and causing economic downturns arising from measures to control COVID-19's impact.

China's effectiveness in containing the pandemic and managing the spread of the disease is reflected in the speed of its economic recovery, which is the best of any major economy.

While its GDP grew at the slowest pace in 40 years, China was still the only major economy in the world to have expanded – by 2.3% – in 2020.[7] This contrasts with the global economy, which was estimated to have contracted by more than 3% in 2020[8], the largest drop in output in the post-war era. Consequently, global primary energy demand fell by almost 4% in 2020, with energy-related CO_2 emissions falling by a little under 6%.[9]

As the Chinese economy returned to its pre-pandemic rate of economic growth, emissions also began to rise. After falling by an average of 10% in each of the first three months of the year, CO_2 emissions rose by an average of 4% in each of the remaining months. Overall CO_2 emissions in 2020 were almost 1% higher than at the end of 2019.[10]

> "China's effectiveness in containing the pandemic and managing the spread of the disease is reflected in the speed of its economic recovery, which is the best of any major economy."

Shell Scenarios *Sketch*

SECTION ONE

ACHIEVING A NET-ZERO CO_2 ENERGY SYSTEM BY 2060

Achieving net-zero emissions in China's energy system over the next four decades will require fundamental changes to the Chinese economy.

Not only will China need to change how energy is produced, the way energy is transported and consumed will also have to be transformed. This will involve developing new energy sources combined with new technologies. New economic and commercial models will also be needed to enable their adoption into industries that directly use energy, as well as the transport and buildings sectors.

Unlike mature economies such as the USA and the EU, China's energy system transformation will need to occur against a backdrop of growing energy demand, as the country achieves economic development comparable to today's advanced economies.[11] This also presents an opportunity for China to overtake currently advanced economies in the development and adoption of low-carbon technologies, fuels and solutions.

PART 1: ACCELERATE CLEAN TECHNOLOGIES AND FUELS

China has been at the forefront of commercialising and deploying low-carbon technologies, such as solar and wind for power generation and electric vehicles for passenger road transport.

Increasing electrification with low-carbon energy

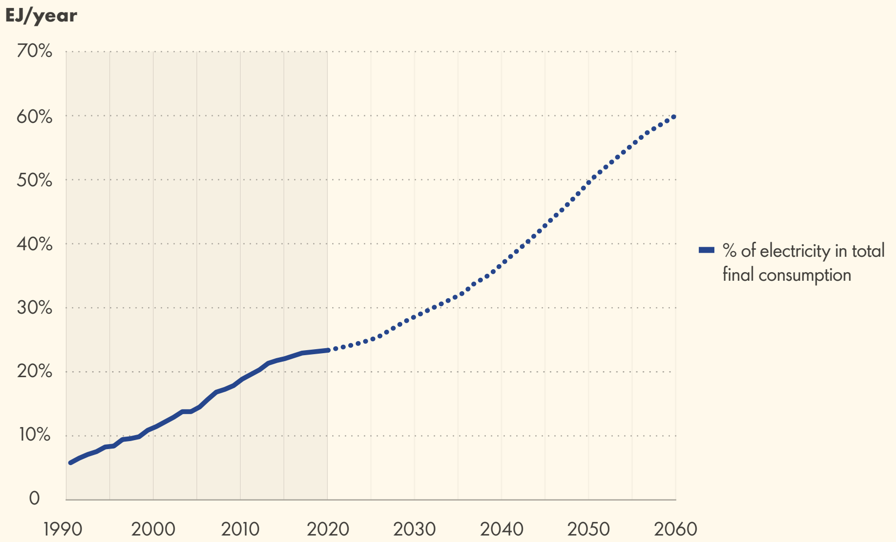
The deep and rapid decarbonisation pathway outlined in this sketch relies on electrifying as much of the economy as possible, while investing in power generation from low-carbon and no-carbon sources, such as renewables and nuclear, to meet electricity demand.

China's electricity system has been growing rapidly since the 1990s. The share of electricity in final energy consumption has grown by about 6% each decade over the past 30 years and will need to grow at an even higher pace – just under 9% – over the next four decades (Figure 1).

In this analysis, electricity's share in final energy consumption rises to almost 60% in 2060, from 23% today, with sectors such as buildings (residential and commercial), light industry and passenger road transport largely electrified.[12]

> "Unlike mature economies such as the USA and the EU, China's energy system transformation will need to occur against a backdrop of growing energy demand, as the country achieves economic development comparable to today's advanced economies."

Figure 1: Rewire China's economy with more electricity



Source: Shell analysis based on historical IEA data

> ...China's electricity system today remains dominated by coal. Decarbonising it will require substantially increasing solar and wind generation from 10% today to 80% by 2060.

In addition to electrifying end-use sectors (industry, transport and buildings), demand for electricity will be driven by the need for hydrogen produced by electrolysis. This is discussed in greater detail in the next section. The exponential increase in hydrogen demand, starting in the 2030s, will add 25% to electricity demand by 2060 and will require an electricity system that is almost four times the size it is today.

Greater electrification needs to go together with a shift to low-carbon and no-carbon sources of electricity generation.

China is a global leader in renewables deployment. Wind capacity (onshore and offshore) increased by 79 GW, or 60%, between 2015 and 2019; solar capacity increased by 161 GW, or a little less than 400%.[13]

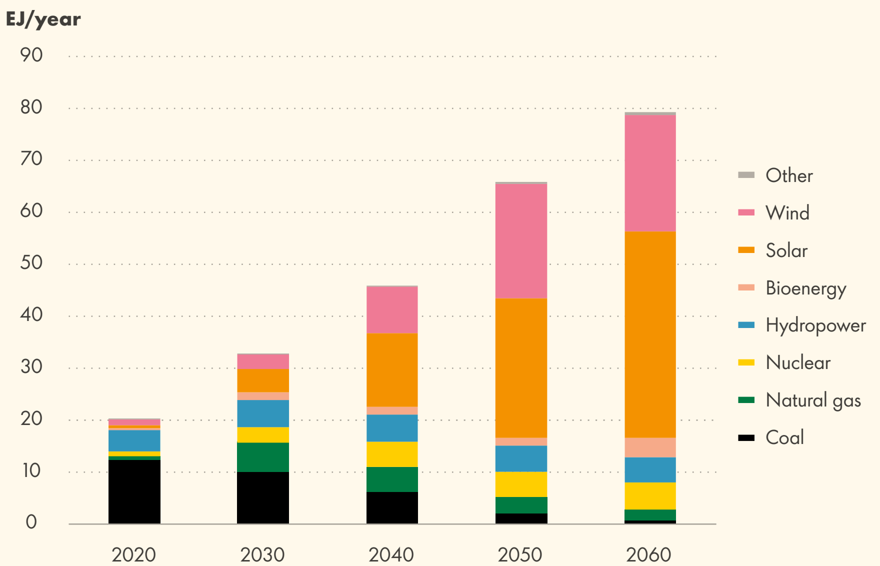
Despite the pandemic, China accounted for about 75 GW – or 80% – of global renewable capacity additions between 2019 and 2020. This was driven in large part by a policy deadline for previously contracted capacity to be connected to the grid by the end of 2020.[14]

However, China's electricity system today remains dominated by coal (Figure 2). Decarbonising it will require substantially increasing solar and wind generation from 10% today to 80% by 2060. In this sketch, solar and wind will surpass coal to become the largest sources of electricity by 2034.

Nuclear has a niche yet important role to play, as does electricity generated from biomass. The latter, combined with carbon capture, utilisation and storage (CCUS), provides a source of negative emissions for the rest of the energy system from 2053. Any electricity generated from fossil fuels in 2060 is fitted with CCUS, with utilisation resulting in permanent storage of the carbon.

Achieving this level of clean electrification will require significant systemic change.

Figure 2: Meet electricity demand with clean electrons



Source: Shell analysis, IEA historical data

One important area of change will be expanding high-voltage transmission line capacity to connect renewables-rich regions, notably in the north and west, with areas of high energy demand on the coast.

China has already been investing in high-voltage electricity transmission lines for more than a decade. It has ambitious plans to further expand the grid to support larger quantities of cleaner electricity.

Milestone projects in recent years include the first green ultra-high voltage power transmission line to connect solar power generated in Qinghai province to users in Henan province, which was opened by the State Grid Corporation of China in 2019. Another is the country's first large-scale wind power network to collect the output of 36 wind farms in Inner Mongolia. This network, established in 2020, will inject power into an ultra-high voltage power line to the coastal provinces of Shandong and Jiangsu.

Another important priority will be investing to enhance distribution networks. Network capabilities will need to be improved to balance diverse sources of electricity supply and demand in real time, while digital technologies and solutions can be harnessed to build an optimised, reliable and resilient grid.

A third area of focus is improving electricity market structures to manage intermittency in a high-renewables power system. For example, adequate incentives are needed for investments in flexible sources of generation, large-scale storage, as well as smart infrastructure and systems, in order to manage fluctuations in demand.

Ensuring greater interconnection between regional and provincial electricity markets, which would lead to more efficient scheduling and balancing of the grid, will also be important for managing costs and ensuring stability of supply. The International Energy Agency estimates that moving from provincial to regional scheduling and balancing will reduce the need for 100 GW of flexible resources between 2021 and 2060.[15] The investment costs and system benefits of flexibility are discussed in more detail in Section 3.

Finally, on the demand side, increased electrification will require new technologies and production processes to electrify transport, light industry and buildings as much as possible. To enable this change, new infrastructure like electric vehicle charging networks will be needed, as will new transport drivetrains and new production processes for heavy industries like steel.

Commercialising low-carbon fuels: hydrogen, biofuels

In this analysis, about 60% of energy consumption will be electrified in 2060. For the remaining 40% of energy consumption in hard-to-electrify sectors, low-carbon molecules will be required.

Sectors such as heavy-duty road transport, shipping and aviation, as well as heavy industries like steel and chemicals, all need portable, high-density fuels. These sectors, which currently rely on fossil fuels, will have to transition to new lower-carbon energy sources in the future.

Hydrogen molecules, in particular, will play an important role in meeting the energy needs of these hard-to-electrify sectors.

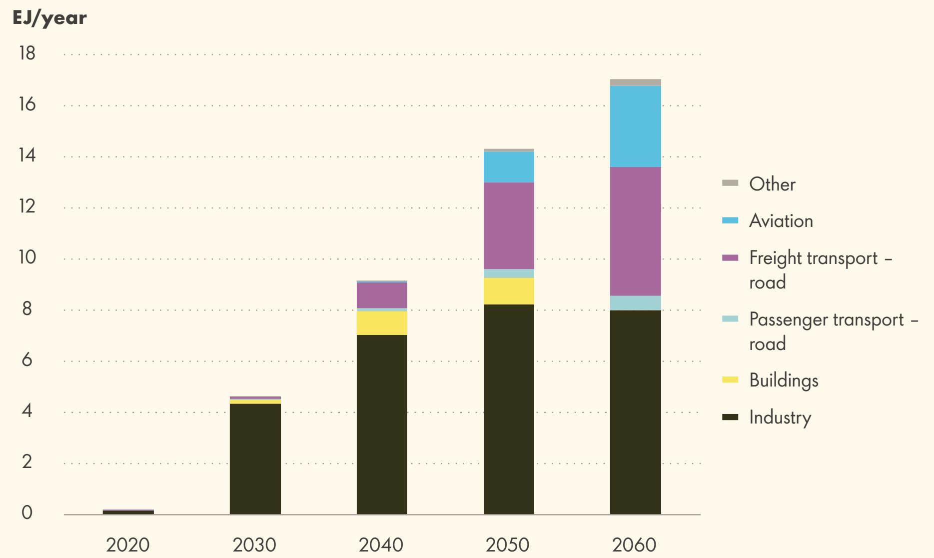
In this sketch, hydrogen scales up from negligible levels today to more than 17 EJ a year by 2060. This is equal to 580 million tonnes of coal equivalent, or 16% of final energy consumption.

Hydrogen will be primarily used in heavy industry, agricultural machinery, heavy-duty road transport, short-haul aviation and shipping (Figure 3), and more than 85% of it will be green hydrogen produced through electrolysis powered by renewable and nuclear electricity. While there is some hydrogen produced from coal and gas in 2060, it is relatively limited and fitted with CCUS.

This scale of deployment by 2060 will mean significant investment is needed to commercialise green hydrogen over the next two decades. The cost of harnessing solar and wind energy has been declining over the past 10 years and will continue to do so, boosting hydrogen's commercial viability. At the same time, the growing use of hydrogen will require investment in production, distribution and storage infrastructure. All these investments need to occur simultaneously: commercialisation projects; initial investments in hydrogen production plants; and pilot projects for hydrogen take-up in end-use sectors like road freight, shipping and steel.

Recognising the importance of hydrogen, both as a low-carbon energy source and as a global growth industry, China's 14th Five-Year Plan (2021-25) names hydrogen as one of six industries of the future. The China Hydrogen Alliance, a government-supported industry group, predicts that hydrogen will make up at least 5% of China's energy system by 2030, which is in line with the analysis in this scenario sketch.

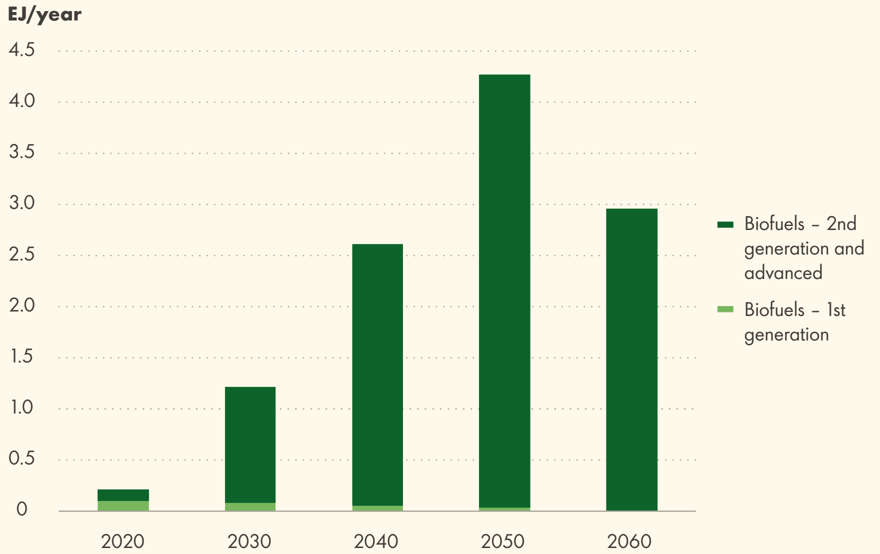
Figure 3: An exponential scale up in hydrogen



Source: Shell analysis, IEA historical data

> Starting in this decade, policies to incentivise advanced biofuels production and to drive down production costs to make them commercially viable for use in sectors like aviation are vital.

Figure 4: Biofuels play a niche, but important role in decarbonising the hardest-to-abate sectors



Source: Shell analysis, IEA historical data

Advanced biofuels will be key for sectors that require higher-density liquid fuels, such as long-haul aviation and chemicals. They represent one of the few foreseeable lower-carbon alternatives for liquid fuels in the near and medium terms.

In our sketch, biofuels increases from relatively modest levels today to almost 5 EJ in 2040 (Figure 4). However, biofuel demand peaks in 2045 and then declines due to two factors: increased electrification, which reduces the need for blending biofuels with liquid fossil fuels in passenger road transport; and increased hydrogen use in heavy-duty road and rail transport.

By 2060, biofuel demand will moderate to less than 3 EJ a year, increasingly met by advanced biofuels, which minimise impact on food production as well as on the wider environment. At the same time, biofuels will need to be high-graded and prioritised to meet the specific needs of the hardest-to-abate sectors like aviation and chemicals.

Starting in this decade, policies to incentivise advanced biofuel production and to drive down production costs to make them commercially viable for use in sectors like aviation are vital. Currently, biofuels in China mainly comprise ethanol produced from conventional starch-based feedstocks and are used in industry and road transport. The country had previously set a target in September 2017 that national petrol supply would contain 10% ethanol from 2020 onwards. But this target has since been suspended due to concerns about its potentially negative impact on the food supply chain.

This presents an opportunity for China to re-focus its biofuel policy on promoting second-generation and advanced biofuels. These have a lower impact on the food supply chain and are more environmentally sustainable.

The government will need to incentivise producers, including those on marginal lands, to make the transition to sustainable biofuels, while advancing policies that create markets and prioritise demand in the hardest-to-abate sectors. One example is the aviation industry, which requires a higher grade of biofuels than road transport. Policies that drive investment in commercialising high-grade advanced biofuels and driving down their costs will be critical to support this sector's energy need for sustainable aviation fuels.

PART 2: SUPPORT ENERGY-EFFICIENT AND LOW-CARBON CHOICES

As low-carbon technologies, fuels and products are brought to market, consumer and business choices can help to strengthen and drive even more change. Strong demand is a powerful incentive for innovation.

Realising full energy efficiency potential

China has made significant gains in energy efficiency over the past two decades, but it still has potential for improvement. Since 2000, the country's total primary energy demand has increased a little less than threefold, while its GDP has increased more than fivefold. This has brought the energy intensity of its GDP down by more than 45% over the last 20 years.

However, China still has room for improvement, especially when compared to European economies. Germany's energy intensity of GDP in 2018 was almost 40% lower than that of China, while the UK's level was almost half.

In this forward-looking sketch, energy efficiency improvements continue at pace over the next four decades. Energy intensity of GDP is estimated to decrease by more than 50% between 2020 and 2060. Economic activity continues to decouple relative to energy use, with GDP growth continuing to outpace energy demand growth over this period (Figure 5).

The trend towards greater low-carbon electrification will drive a significant portion of the overall energy efficiency improvement.

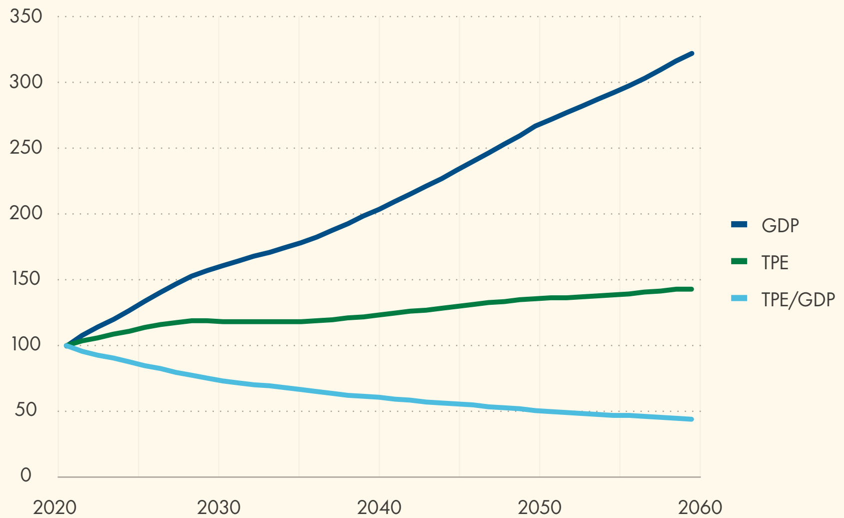
In transport, electric vehicles, which are 90% efficient in converting the energy input into kinetic energy to drive the vehicle forward, will increasingly replace internal combustion engines that convert 60-80% of energy input into heat.

In industry, energy efficiency will be boosted through better industrial processes. This includes electrification of light industry.

In residential and commercial buildings, energy efficiency will need to be significantly raised by upgrading and insulating existing stock, while implementing and enforcing tighter construction standards for new buildings.

"As low-carbon technologies, fuels and products are brought to market, consumer and business choices can help to strengthen and drive even more change."

Figure 5: China's energy demand continues to decouple relative to economic growth



Source: Shell analysis, IEA historical data

In urban environments, economic activity tends to be concentrated, so harnessing digital technologies can go a long way to boost energy efficiency through smart, integrated infrastructure for transport, housing, offices, energy, waste, water and other urban services.

Gradually raising the carbon price

A rising carbon price[16], whether implemented through market or regulatory approaches, is essential for China to achieve net-zero emissions by 2060.

In this sketch, the carbon price – which includes both explicit carbon tax/price and implicit regulatory costs – initially rises slowly to CNY 300/tCO_2 in the years to 2030. It then ramps up more quickly in subsequent decades, eventually reaching CNY 1,300/tCO_2 by 2060 (Figure 6).

A rising carbon price is a key lever to create a level playing field for lower-carbon energy. Its role is expected to shift over the course of this transition:

- As the carbon price ramps up this decade, its gradual rise will prompt more efforts to improve energy and emissions efficiency in sectors like transport, buildings and industry. It also begins to drive the reallocation of resources across the economy – especially capital – towards lower-carbon technologies and infrastructure. In particular, the carbon price has been shown to be effective in driving the switch out of coal, such as in Europe.

In the initial phase, the carbon price is most effective when it is implemented as part of a comprehensive clean energy policy framework. This framework incentivises innovation and includes policies that bring clean technologies, fuels and products to market, while supporting their deployment and large-scale adoption through infrastructure planning.

Considering that the rate of increase in carbon price will accelerate after 2030, this will allow time for innovation to flourish and for new low-carbon solutions to be developed.

This, in turn, provides consumers and businesses with a broader range of low-carbon options to choose from.

- Once these low-carbon solutions get close to commercial viability and the infrastructure to facilitate their adoption at scale has been established, the carbon price has an important role to play: driving the switch from fossil fuels to low-carbon energy, and shifting consumer and business choices more widely towards low-carbon products and services.
- In the longer term, cleaner alternatives are likely to become cost competitive with fossil fuels in some sectors such as power and passenger road transport. However, other sectors such as aviation are likely to require a sustained and high carbon price to bridge the gap to clean technologies and fuels.

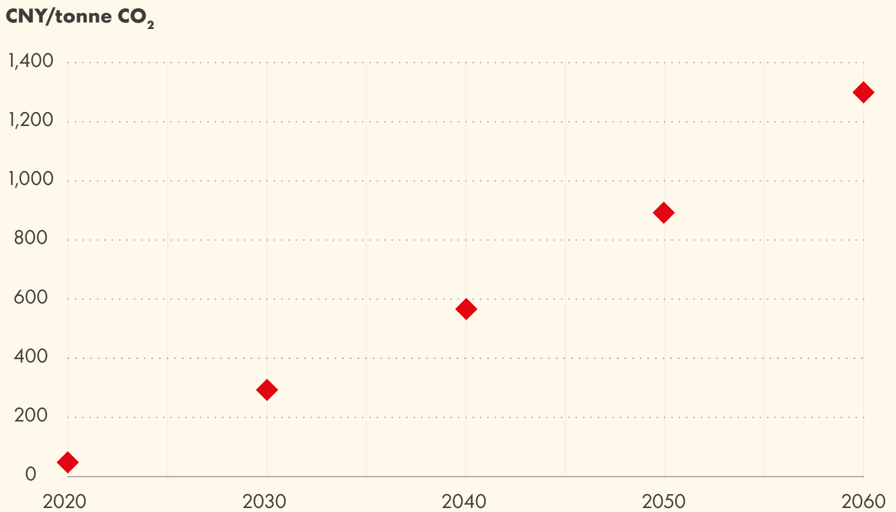
China has experience in carbon pricing through seven regional emissions trading schemes (ETS). This culminated in the establishment of a national emissions trading scheme. Building on the experience of the regional pilots, the national ETS began trading in July 2021. It is currently focused on the power sector, covering more than 4 billion tonnes of CO_2. As the largest emissions trading system in the world, it covers around 40% of China's total carbon emissions.

The scope of the national ETS is expected to expand in the next phase of development to include other sectors of the economy, such as emissions-intensive industries like steel and chemicals. It could also include more financial players to provide market liquidity and other benefits.

The design features of the ETS are also expected to evolve. These may include shifting from the current intensity-based cap on emissions to an absolute cap on emissions, and from the current free allocation of allowances towards greater auction-based allocation.

Systematic development and implementation of the national ETS will be key to driving China along a cost-effective pathway to carbon neutrality, by providing the clear and consistent price signal required for the energy system to reach net-zero emissions by 2060. Establishing a meaningful carbon price this decade – to drive the switch away from coal, for example – will be crucial to its long-term robustness and credibility.

Figure 6: The carbon price rises continuously between now and 2060



Source: Shell analysis, IEA historical data

> Retrofitting existing coal-fired power plants – as well as industrial facilities such as chemical, cement, and iron and steel plants – with CCUS can provide a means of reducing emissions, without having to prematurely retire these assets.

PART 3: REMOVE CARBON EMISSIONS

Scaling up CCUS

The urgency of mitigating global climate change makes it imperative for China to achieve net-zero emissions within a relatively short timeframe of 40 years. A shift to cleaner energy sources and energy efficiency will not be enough. China will also need to actively remove emissions as well.

This makes carbon capture, utilisation and storage (CCUS) an essential part of the solution for China. The country has to contend with numerous coal-based power and heavy industry facilities, which were built in the last decade and have many years of economic life remaining.

Retrofitting these existing coal-fired power plants – as well as industrial facilities such as chemical, cement, and iron and steel plants – with CCUS can provide a means of reducing emissions, without having to prematurely retire these assets.

There are several ways to apply CCUS. These include new technologies that are being developed to capture CO_2 directly from the air; capturing emissions created during industrial processes; capturing emissions from energy use in industry and power; and capturing emissions associated with the production of hydrogen from coal and natural gas.

Using captured CO_2 – in order to enhance oil recovery or to create synthetic fuels and chemicals, for instance – can play an important role in the transition to net zero. It may help displace fossil fuels in the short term and provide an additional revenue stream to support the commercialisation of carbon capture. However, captured CO_2 will eventually need to be restricted to uses which involve permanent – or near-permanent – geological storage.

China has significant geological potential for storing carbon: an estimated 2,400 gigatonnes (Gt) in storage capacity, second only to the USA.[17] It currently has more than 40 CCUS pilot projects with a total capacity of 3 million tonnes.[18] Many of these projects are small developments linked with enhanced oil recovery. This will need to scale up significantly over the next four decades.

In a net-zero emissions energy system, a little more than 1.3 Gt of CO_2 a year will need to be captured and permanently stored in 2060 (Figure 7). This means CCUS capacity will need to increase more than 400 times in the next four decades. While this is technically possible, as many of the CCUS technologies in China are close to or have reached commercialisation, the main challenge lies in creating conditions to support substantial investment in large-scale CCUS, particularly as a solution to industrial decarbonisation.

BOX 1: THE ROLE OF INDUSTRIAL CLUSTERS AND PORTS IN SCALING CCUS

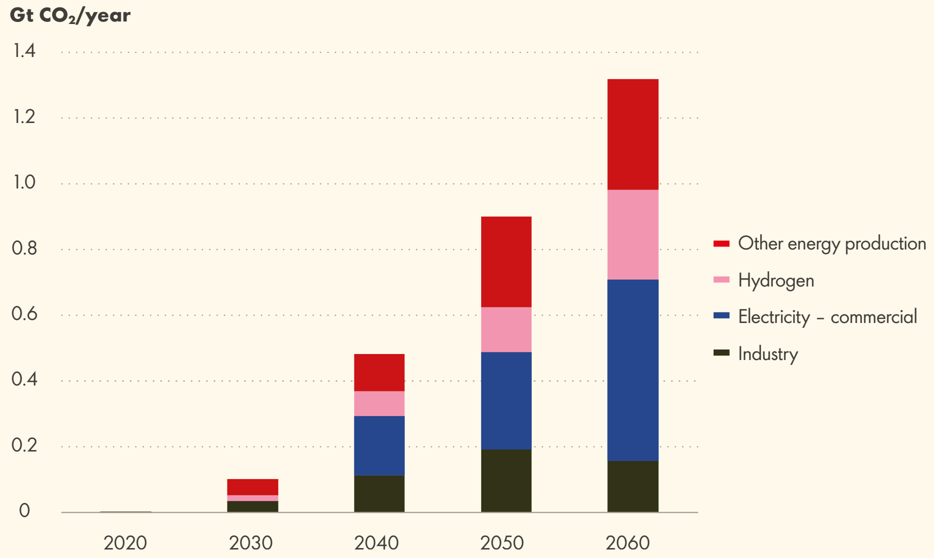
Industrial clusters and ports will play an important role in accelerating the development of CCUS in China. Scaling will be a key differentiator between future large-scale projects and previous pilots and small stand-alone projects. In this context, clustering emission sources and sharing infrastructure can provide the benefits of scale.

The International Energy Agency estimates that 45% of the CO_2 emissions from China's power generation and heavy industries are within 50 kilometres of potential CO_2 storage, and 65% are within 100 kilometres.[19]

- Industrial clusters comprising high-emission enterprises and industries provide economies of scale for building CO_2 capture, transport and storage infrastructure. They can also provide an opportunity to pilot the required regulatory frameworks. For example, provinces like Shanxi, Shaanxi and Xinjiang, which have a high concentration of coal-based industries, may be suitable pilots.
- Ports also provide an early opportunity for CCUS development due to: their proximity to potential offshore storage sites; the decarbonisation potential of large industrial ports; and economies of scale for building CO_2 management infrastructure. Ports with such characteristics include the industrial ports on China's east coast, such as Guangzhou.

In the long term, integrating CCUS technology into the development of industrial clusters and ports has the potential to achieve large-scale emission reductions in China. This will be particularly relevant for hard-to-abate industrial sectors that are likely to dominate China's economy for some decades to come.

Figure 7: Scaling up CCUS



Source: Shell analysis, IEA historical data

Public policy action is needed starting now to achieve this scale of CCUS by 2060. Action would include a robust and rising carbon pricing mechanism to make CCUS commercially viable in the long term.

In addition, rewarding CCUS emission reductions, such as through carbon credits in the national ETS, will drive greater investment in the technology.

In the short term, policy action would need to include support for commercialising capture technology for direct air capture and for various end uses, particularly in power generation and industry. Developing CO_2 transport infrastructure – such as trucks, rail and barges for short distances and ships and pipelines for longer distances – is also needed.

Policy frameworks that reduce investment risk and capital costs will attract private capital in the near term. Other measures, such as clarifying long-term liability requirements for permanent carbon storage, will facilitate greater market adoption.

“In the short term, policy action would need to include support for commercialising capture technology for direct air capture and for various end uses, particularly in power generation and industry.”

BOX 2: BIOENERGY AND NEGATIVE EMISSIONS

Advanced biofuels and biomass have a significant role to play in decarbonising China's energy system, particularly in power and in hard-to-abate sectors like aviation and heavy industry.

In this sketch, total bioenergy – liquid biofuels and solid biomass – rises from around 2 EJ today to almost 17 EJ in 2060. This is consistent with estimates of sustainable bio-feedstock potential in China, taking into account factors such as the conversion of marginal lands for cultivation of woody biomass and energy crops.

A systematic and coordinated approach will be vital to fully realise China's sustainable bio-resource potential.

On the supply side, China needs to:

- transition from first-generation biofuels to second-generation and other advanced feedstocks;
- scale up the bioenergy supply chain through the development of systems to collect and transport the feedstock, as well as scale advanced bioenergy production capacity; and
- introduce policies to encourage and incentivise sustainable bio-resource production.

These policies will need a strong regional focus, as the availability of different types of biomass and biomass-based products will vary widely across the country.

On the demand side, China needs to:

- transition away from the traditional use of biomass for residential cooking, heating and in biofuels for road transport, towards the use of advanced bioenergy in sectors like power, heavy industry and aviation.

Applying carbon capture and storage (CCS) to bioenergy – in terms of the production of liquid biofuels or of solid biomass – can be a source of negative emissions. As discussed previously, electricity generated from biomass is an important element of China's decarbonised electricity system, accounting for around 6% of power generated in 2060. In addition, China's industry sector is currently a significant consumer of biofuels, with advanced bio-resources likely to continue to be required in sectors such as chemicals. Based on the analysis in this sketch, total commercial biomass in 2060 will account for about 6% of total final energy consumption in heavy industry.

Applying CCS to biofuels or biomass production and use does not just reduce CO_2 emissions. It is also a source of negative emissions for the energy system overall. In this analysis, bioenergy with CCS (or BECCS) accounts for around 42% of the CO_2 captured in 2060, or 0.6 Gt of negative CO_2 emissions.

The relatively young age of China's power and industrial facilities also makes bioenergy an attractive option for reducing emissions. Biomass can be used as a drop-in fuel and/or co-fired with coal as a way of reducing emissions from these facilities without significantly changing the production process. This can help avoid potentially costly early retirement of these assets. Retrofitting them with CCS can help extend their life – not as a source of emissions, but as a way of reducing emissions instead. China also currently generates significant amounts of electricity and heat from waste, and these facilities provide another early opportunity for creating negative emissions through their conversion to biomass with CCS.

> Advanced biofuels and biomass have a significant role to play in decarbonising China's energy system, particularly in power and in hard-to-abate sectors like aviation and heavy industry.

Shell Scenarios sketch

SECTION TWO

CHINA'S ENERGY SYSTEM IN 2060

China's transition to net zero leads to a radically different energy system in 2060. This analysis sets out a unique pathway for achieving net-zero emissions from energy over the next four decades:

It is based on:

1. deep electrification of the economy and the technical and economic potential of various low-carbon technologies and fuels;
2. realising the full potential from energy efficiency and low-carbon consumer and business choices; and
3. use of carbon removals for the most difficult and expensive emissions to abate.

While variations on this pathway are possible, achieving carbon neutrality by 2060 will require action across all three areas. Societal and policy preferences will determine the relative balance of effort between them.

To achieve carbon neutrality, deep reforms will be needed to fundamentally transform China's energy system, both at an economy-wide and sectoral level.

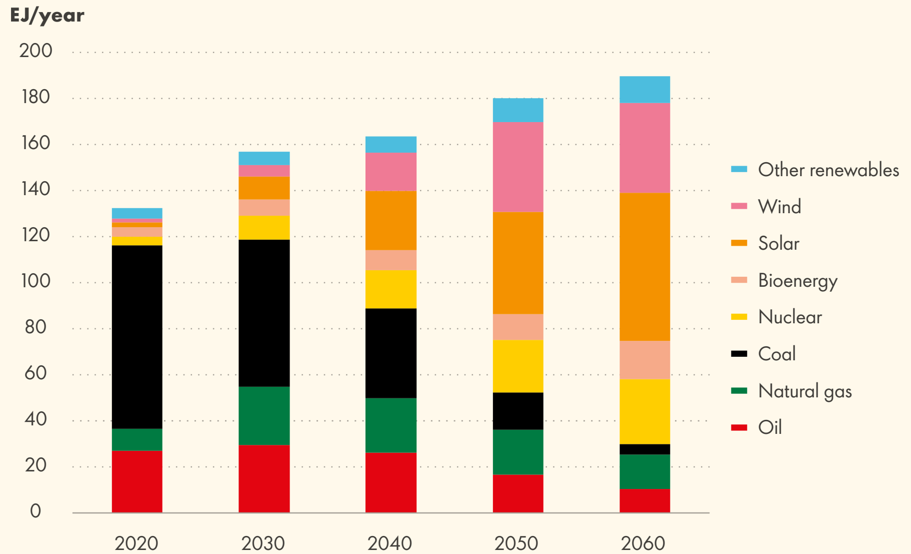
ECONOMY-WIDE PERSPECTIVE

China's energy mix needs to change from fossil-dominated today (88% of primary energy) to one dominated by low-carbon and no-carbon energy - with 80% of primary energy derived from solar, wind, bioenergy and nuclear - by 2060 (see Figure 8 and Box 2).

Unlike developed economies such as the USA and EU, China's energy transformation needs to occur against a backdrop of a still-developing economy and rising energy demand. In this decade, the country will likely reap significant energy efficiency gains. As China's economy matures, it will allow energy demand growth to moderate in the 2030s. From 2040, there is still some moderate growth in energy demand, underpinned by widespread demand for low- and no-carbon fuels such as green hydrogen.

“Unlike developed economies such as the USA and EU, China's energy transformation needs to occur against a backdrop of a still-developing economy and rising energy demand.”

Figure 8: China transforms its energy mix



Source: Shell analysis, IEA historical data

Changes in how energy is produced are matched by a transformation in how energy is consumed (Figure 9). There is large-scale electrification of end-use sectors such as buildings, road transport and light industry. This, along with other supply-side and demand-side energy efficiency improvements, results in final energy consumption being 39% lower than it would have been otherwise.

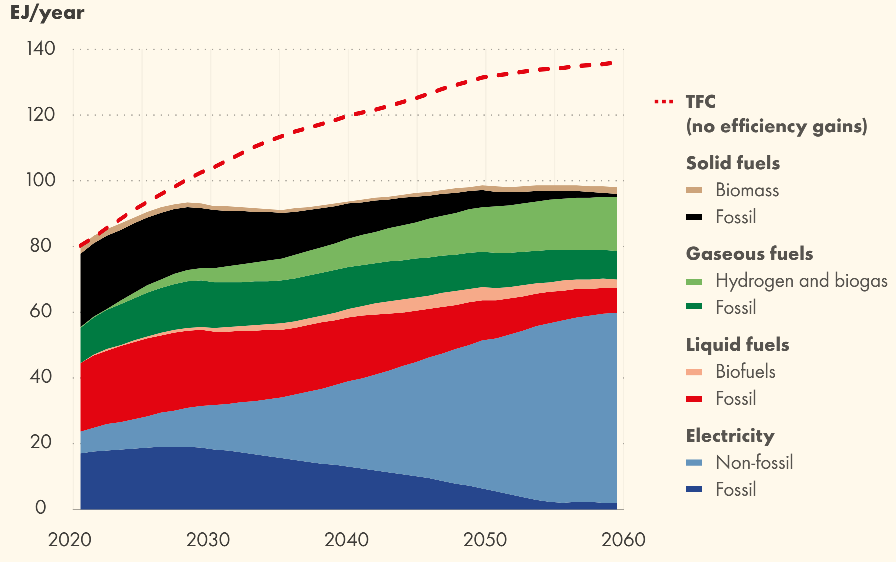
> Difficult-to-electrify sectors continue to rely on molecules. However, these molecules shift from natural gas to gases such as hydrogen, from oil to sustainable liquid biofuels, and from coal to sustainable biomass.

Difficult-to-electrify sectors continue to rely on molecules. However, these molecules shift from natural gas to gases such as hydrogen, from oil to sustainable liquid biofuels, and from coal to sustainable biomass.

In this sketch, China achieves net-zero emissions in its energy system by 2060, with all sectors getting as close to zero CO_2 emissions as possible. Energy-related CO_2 emissions fall from about 10 Gt today to about 2 Gt in 2050 and reach net zero by 2060.

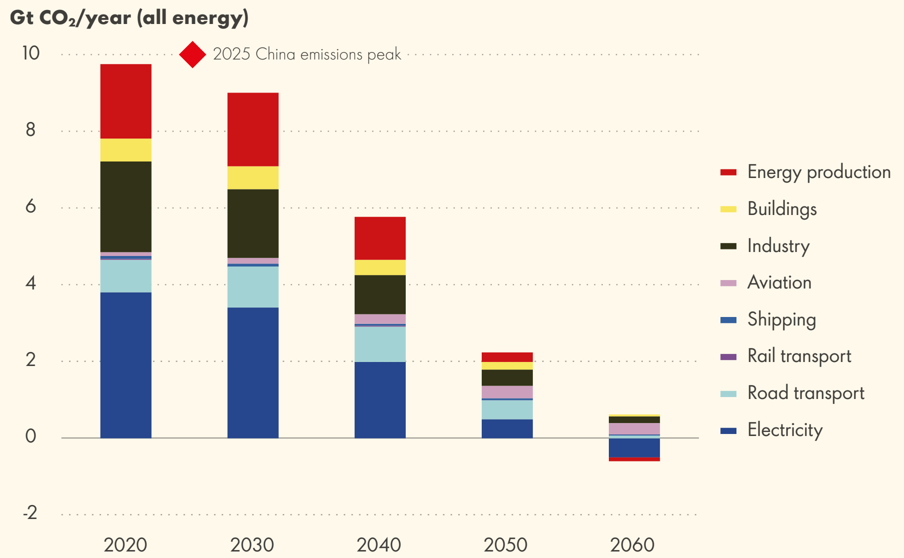
The sketch envisions a combination of low-carbon technologies and fuel sources; energy-efficient behaviours and low-carbon choices; and carbon removal through CCUS in the hardest-to-abate sectors. This includes bioenergy with carbon capture and storage (BECCS) in power and industry to create negative emissions (Figure 10).

Figure 9: China transforms its energy system



Source: Shell analysis, IEA historical data

Figure 10: Decline in energy CO_2 emissions

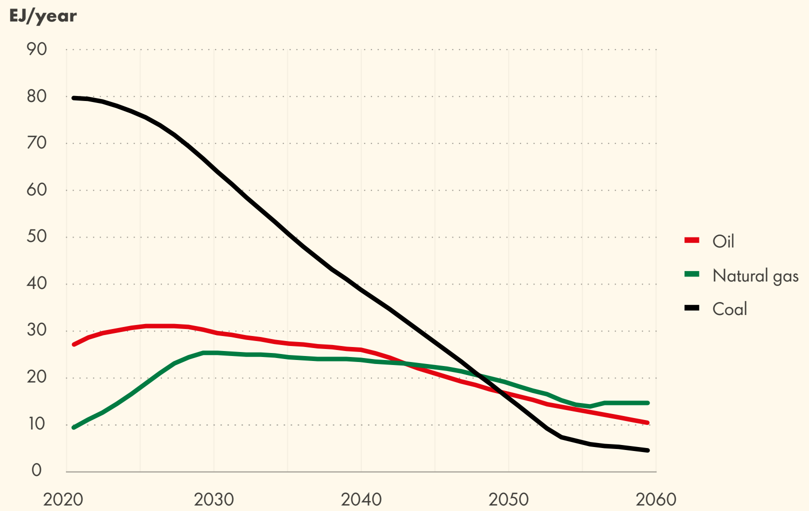


Source: Shell analysis, IEA historical data

BOX 3: FOSSIL FUELS

The role of fossil fuels in total primary energy declines dramatically in China's energy system, particularly after 2030. This analysis assumes that China's coal demand has already peaked and begins to significantly decline from the mid-2020s (Figure 11). Natural gas demand plateaus in the 2030s and 2040s and then declines. Oil peaks in the 2020s, and then gradually declines, driven by the electrification of passenger and light-duty road transport vehicles. Some fossil fuels remain in the energy mix in 2060, requiring CCUS and negative emissions from BECCS.

Figure 11: Outlook for fossil fuels



Source: Shell analysis, IEA historical data

SECTORAL PERSPECTIVE

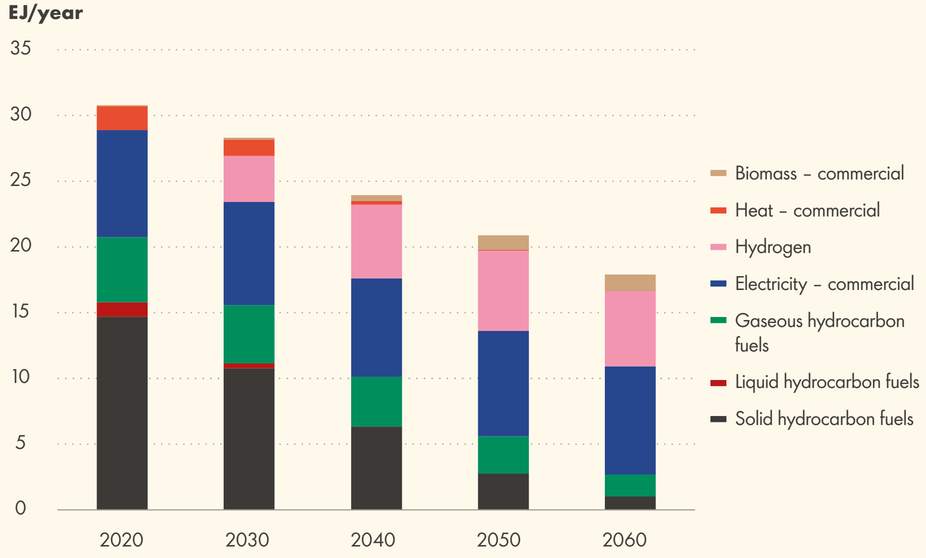
As discussed previously, transforming China's energy system requires changing both energy supply and energy end-use sectors, particularly the hard-to-abate segments of transport and industry.

Today, industry makes up 24% of China's total energy-related CO_2 emissions, while transport accounts for 11%.

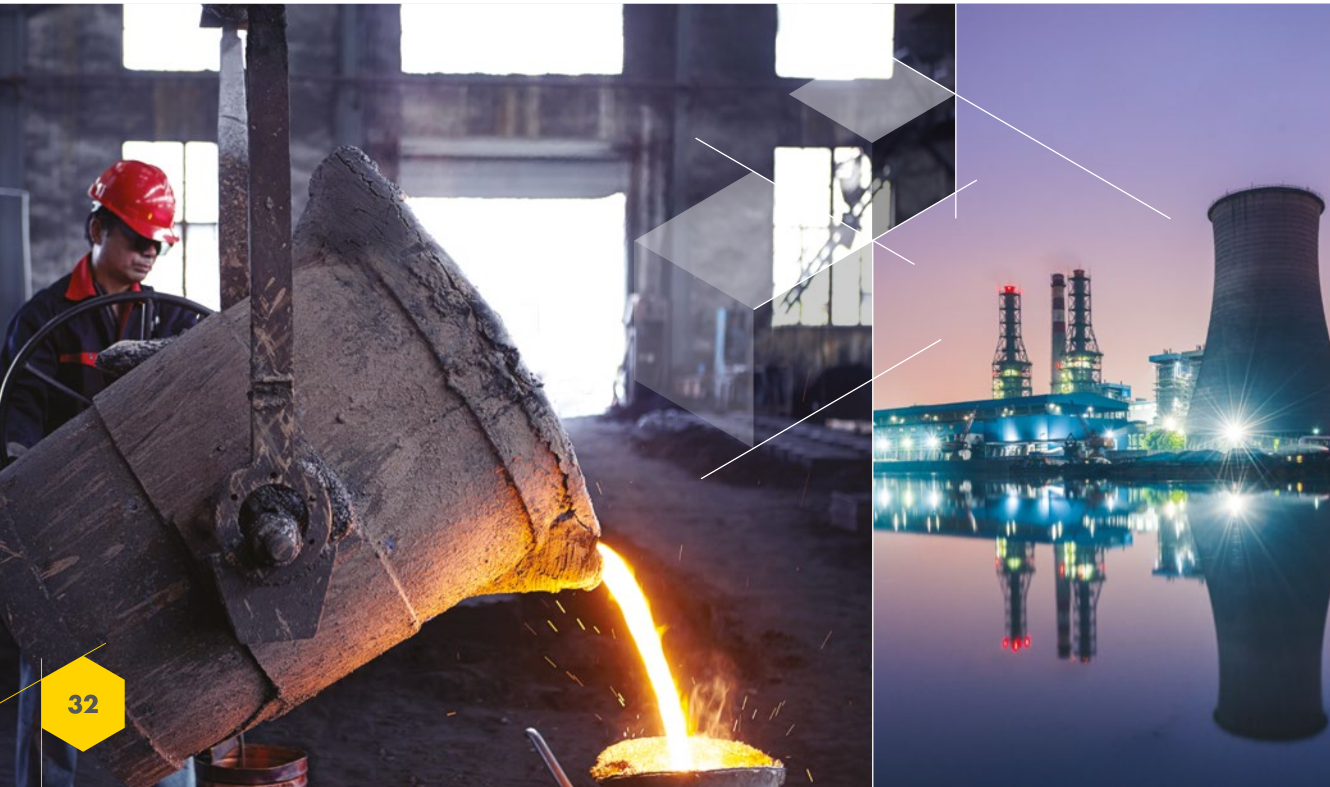
Light industries are relatively easy to electrify, but heavy industries require energy-dense fuels that provide a high thermal load. The challenges are magnified because of the scale of China's hard-to-electrify heavy industries, many of which are the world's leaders. For example, the country currently produces nearly 60% of the world's cement and crude steel, as well as 30% of key industrial chemicals. Its chemical industry is not just the biggest in the world, but also China's largest industrial sector in terms of economic value added.

> Today, industry makes up 24% of China's total energy-related CO_2 emissions, while transport accounts for 11%.

Figure 12: Decarbonising heavy industrial energy demand



Source: Shell analysis, IEA historical data



This sketch anticipates a significant 40% decline in final energy consumption from heavy industry between now and 2060. This is due to the structural shift under way in the Chinese economy towards services and high-value manufacturing, as well as expected improvements in industrial energy efficiency (Figure 12).

That said, heavy industry will remain a significant source of energy demand and consumption. Therefore, industries such as steel, cement and chemicals will need to prioritise the replacement of coal with low-carbon hydrogen and bioenergy as their primary energy source.

This will require significant investments – starting in this decade – to develop and commercialise new production processes based on low-carbon energy, such as steel produced using green hydrogen and chemicals produced using bioenergy.

> "...heavy industry will remain a significant source of energy demand and consumption. Therefore, industries such as steel, cement and chemicals will need to prioritise the replacement of coal with low-carbon hydrogen and bioenergy molecules as their primary energy source."

Investments to fit China's heavy industrial capacity with CCUS will also be needed to keep these relatively young facilities in operation while reducing emissions.

In transport, the passenger road and rail segments are relatively easy to electrify.

However, decarbonisation solutions for other segments such as heavy-duty road transport, long-distance shipping and long-haul aviation are more expensive. These solutions are also further from commercialisation.

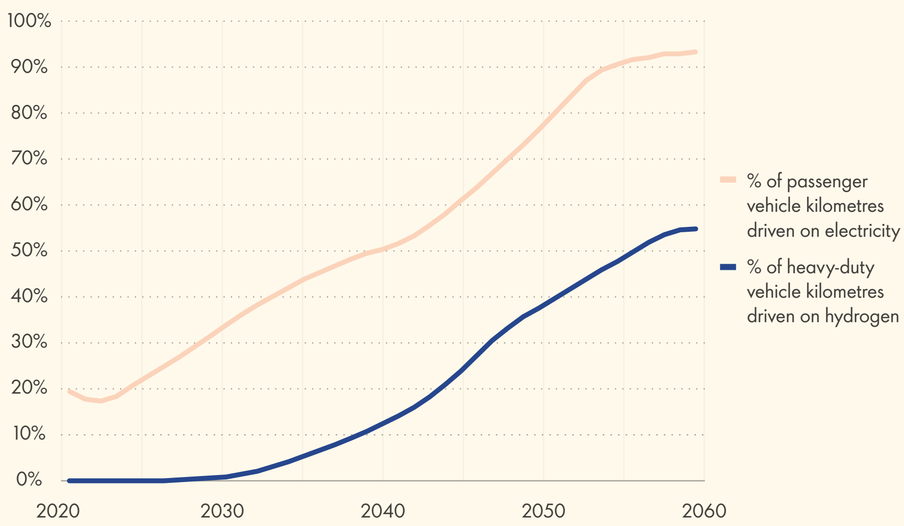
In this sketch, all new passenger vehicle sales from 2040 are EVs (compared to 5.7% in 2020), with EVs accounting for 85% of the passenger vehicle fleet and more than 90% of kilometres driven in 2060 (Figure 13). The heavy-duty road transport segment is less easy to electrify. By 2060, 55% of kilometres driven by heavy-duty vehicles in China will be fuelled by hydrogen. Emissions from shipping and aviation will be the hardest to abate, requiring a combination of hydrogen and biofuels.

Transforming China's energy system will not just require changing energy supply, but also transforming end-use sectors to adopt low-carbon energy, such as through low-carbon drivetrains and propulsion technologies.

While passenger EVs are expected to become cost competitive this decade, the technologies for other transport segments are further from commerciality. China is making a concerted push to develop hydrogen technology and infrastructure in heavy-duty road transport, particularly through incentives to city governments.

China's domestic shipping and aviation sectors are large and still growing. However, its substantial and growing share of global aviation and shipping puts it in a leading position to pioneer new solutions, both to create momentum for change and benefit from it.

Figure 13: Decarbonising road transport



Source: Shell analysis, IEA historical data

BOX 4: OPPORTUNITY FOR NATURE-BASED SOLUTIONS

While our analysis does not require nature-based solutions (NBS) for China's energy system to reach net-zero emissions by 2060, natural carbon sinks provide an additional lever to support the transition. For example, forests can provide bioenergy and act as natural carbon sinks.

China has an estimated technical potential to reduce CO_2 emissions through reforestation by up to 1 Gt a year by 2050. These natural sinks can help offset emissions from fast-growing sectors like aviation, heavy industry and road transport, as they transition to net zero. To the extent that forests are sustainably managed as a source of bioenergy, they provide a carbon-neutral alternative to fossil fuels; they are also a natural carbon sink if left untouched and could become a negative source of emissions if used for BECCS (see Box 2).

China has made significant progress in increasing forest cover, which has almost doubled since the 1970s and 1980s to around 23% in 2020. Since 2005, the volume of forest stock has risen by 4.5 billion cubic metres, capturing an estimated 480 million tonnes of CO_2 annually over the last 15 years. The 14th Five-Year Plan targets to increase forest cover to 24% – equivalent to 19 billion cubic metres in forest stock volume – by 2025.

China has also committed to increasing grassland vegetation coverage. Encouraging farmers to adopt practices that enhance soil carbon could be another significant natural carbon sink. These options can be part of China's measures to peak its emissions by 2030 and achieve carbon neutrality by 2060.

There has been a pilot carbon sink trading project in operation in Inner Mongolia since 2014. It allows companies to purchase carbon sinks in order to offset excess emissions above their cap. With a proliferation of such schemes, monitoring, reporting and verification will be even more critical to ensure the offsets are of the highest quality and the schemes do not undermine carbon mitigation activities and investments.

Shell Scenarios Sketch

SECTION THREE

MAKING PROGRESS TOWARDS CARBON NEUTRALITY

Achieving a net-zero emissions energy system in China by 2060 will be extremely challenging, but we believe it is possible to achieve through an alignment of interests across government, businesses, consumers and citizens. Managing the impacts requires enhancing the advantages and managing any disadvantages from the transition. In turn, this will require:

- understanding the impacts of the energy transition;
- creating comprehensive policy frameworks;
- establishing sectoral coalitions for action; and
- maximising the potential of cities as incubators for change

UNDERSTANDING THE IMPACTS OF THE ENERGY TRANSITION

The energy transition will affect virtually every aspect of economic and societal activity. Understanding the many implications of China's energy transformation will be critical to making progress, by enhancing the benefits of this transition while managing any negative effects.

Macroeconomic impact

Cost concerns are a common obstacle to decarbonisation efforts. But costs can also be recognised as investments in an economy's future growth, generating benefits in terms of jobs and overall demand.

The Energy Transitions Commission estimates that transitioning to a no-carbon emissions economy will have a modest – less than 0.5% – impact on 2050 living standards in developed and developing countries alike.[20] On the other hand, if society does little to mitigate climate change, there could be substantially greater negative economic and social impacts: from rising sea levels, agricultural and biodiversity effects of changing weather patterns, and greater frequency of extreme weather events.

In line with global and country-specific estimates, the overall resource cost to the Chinese economy of making the transition to net zero is relatively modest: the eventual impact on GDP per capita and standard of living is estimated to be less than 1%.[21] In the long term, a net-zero emissions energy system could even produce economic benefits. For example, the system costs in terms of power generation and flexibility of a low-carbon power system in China in 2050 are estimated to be lower than that of today's fossil-based power system.[22]

> “The energy transition will affect virtually every aspect of economic and societal activity. Understanding the many implications of China's energy transformation will be critical to making progress...”

These macroeconomic effects are relatively small compared to the massive reallocation of investments and resources needed across China's large economy to achieve carbon neutrality by 2060. For example, as a share of global GDP, annual average energy-related investments to support the energy transition to net zero are estimated to be just 1% higher than in recent years.[23] However, in terms of energy supply, it requires a significant reallocation of investment from fossil fuels towards low-carbon electricity and low-carbon fuels like hydrogen and advanced biofuels.

A case in point is large-scale electrification with low-carbon sources of electricity. This means an electricity system dominated by variable renewables such as wind and solar. Managing the intermittency of these low-carbon sources – for instance, when the sun is not shining or the wind is not blowing – requires a significant increase in power system flexibility to ensure sufficient supply to meet demand and to maintain grid stability.

A variable renewable power system with the requisite system flexibility could bring net savings of $132 billion per year by 2050, reducing electricity prices by up to 18%. This is due to lower capital costs, zero marginal operating costs, and rapidly declining installation costs of solar and wind capacity.[24]

Unlocking these benefits will require significantly greater investment in system flexibility such as energy storage, flexible low-carbon power generation, transmission network reinforcement and interconnections, and demand-side response. This could cost $96 billion a year by 2050, compared to the roughly $25 billion invested to-date in the present fossil fuel dominated power system.

The transition to low-carbon energy will also require substantial reallocation of capital towards new energy infrastructure.

We estimate that achieving carbon neutrality by 2060 will require infrastructure investments in the range of $12.5 trillion between 2020 and 2060, with more than half needed over the next two decades. This is necessary for early decarbonisation of the power sector to ensure that China is well placed to extend low-carbon electricity to decarbonise end-use sectors. Early infrastructure investments this decade also provide benefits in terms of

“A variable renewable power system with the requisite system flexibility could bring net savings of $132 billion per year by 2050, reducing electricity prices by up to 18%.”

supporting economic recovery and creating a green and sustainable future (Box 5).

Infrastructure related to bioenergy, hydrogen and CCUS will also see large increases in investment – particularly from the 2030s onwards – as technologies and markets mature and they are deployed to reduce emissions in hard-to-electrify sectors.

Significant investments are also required in energy demand sectors (transport, industry and buildings). These will be used to boost energy efficiency and develop new technologies, production processes and drivetrains that run on low-carbon energy. In total, the International Energy Agency estimates annual energy-related investments – for supply, demand and associated infrastructure – in China will need to increase to $900 billion in 2030, rising to $1.2 trillion by 2060.[25] Investments in low-carbon energy demand technologies will dominate, particularly in the later decades. For example, in the 2050s, around 80% of these investments will relate to heavy industries and long-distance road freight, shipping and aviation.

Regional impact

The significant reallocation of resources will mean a shift in economic activity at the provincial and regional level.

BOX 5: INVESTING IN A GREEN RECOVERY

Investing in clean energy this decade could provide an additional boost to economic growth as the global economy recovers from the pandemic.

The enormous disruptions inflicted by COVID-19 on the global economy have triggered a spike in government spending, as countries seek to mitigate the fallout and support economic recovery.

Directing some of this spending towards clean energy investments can both stimulate demand in the short term and support climate-sustainable growth in the long term. Examples of green investments include:

- extending, expanding and upgrading to a smart power grid;
- expanding electric vehicle charging networks;
- building hydrogen transport and storage infrastructure;
- renovating and retrofitting the building stock; and
- scaling up CCUS.

The historically low cost of capital also provides an opportunity for bringing in private investment, through fiscal and other financial incentives, economic recovery packages conditional on companies' environmental performance, and public-private partnerships.

The outcome of investments in clean energy and energy infrastructure this decade could well be win-win: this would not only put the global economy firmly on a net-zero trajectory, but also boost global GDP by 4% compared to current trends, according to a joint analysis by the International Energy Agency and the International Monetary Fund.[26]

As the world's largest producer and consumer of coal, China's shift away from this fossil fuel will have major implications for provinces like Inner Mongolia, Shaanxi and Shanxi, which account for more than 75% of domestic coal production.

As energy supply shifts towards low-carbon sources, fossil-based energy-producing provinces and regions will need to diversify away from coal. However, this also creates new opportunities for some of these regions. For example, Inner Mongolia leads the country in installed onshore wind capacity, while Xinjiang leads in solar photovoltaic capacity.

The energy transition will also create new opportunities for other low-carbon energy sources and technologies. For example, the exponential increase in hydrogen demand will create opportunities for provinces with cheap renewable resources.

Carbon capture, utilisation and storage (CCUS) presents opportunities for provinces such as Shandong that possess suitable onshore and offshore geology to create low-carbon industrial hubs located, for example, near biomass-fired power plants and industrial energy demand centres.

China also has significant bio-resources, ranging from second-generation and advanced bio-feedstocks to agricultural residues and municipal solid waste, which are conducive to creating a bioeconomy to meet the scale of anticipated demand.

Based on the scale of demand for bio-resources set out in this sketch, the bioenergy supply chain could grow from $12 billion in 2020 to $150 billion of value added in 2060, and support a total of 19 million jobs in 2060. It could significantly boost the rural economy, through opportunities in bioenergy crop production and the construction, operation and maintenance of bioenergy (biomass and biofuel) processing and refining plants. The higher costs of transporting feedstocks compared to refined fuel mean that it makes economic sense to co-locate biofuel processing and refining with feedstock production, creating rural bioenergy hubs. It is estimated that in the future, bioenergy could account for around 13% of current agriculture gross value added and 10% of current agriculture jobs.[27]

Realising this potential will require investments now to:

- upskill and retrain rural workers to move into higher-value biofuel production activities;
- develop more sustainable second-generation and advanced bio-feedstocks that minimise environmental and food chain impacts;
- reallocate resources of state-owned enterprises that currently own and operate bioenergy processing and refining plants; and
- attract new private investment into a new rural growth industry.

Sectoral impact

The reallocation of resources across the economy will challenge some traditional industries and present opportunities for new growth industries.

As the world shifts towards low-carbon energy, demand for low-carbon fuels, technologies, products and solutions will accelerate. China is well placed to be at the forefront of these new growth sectors. It has a large domestic market for low-carbon products and solutions, as well as an already significant manufacturing base in these areas to build on. For example, 45% of the global stock of passenger electric vehicles in 2020 – 4.5 million – were in China.[28] Nearly half of the world's plug-in electric car production and 90% of heavy-duty electric vehicle production in 2020 was also located in China.[29]

> It is estimated that in the future, bioenergy could account for around 13% of current agriculture gross value added and 10% of current agriculture jobs.

> China already leads the world in the manufacture of batteries, solar photovoltaic and electric vehicles (battery and fuel cell), and is second only to Europe in electrolyser manufacturing capacity.

China accounts for a large share of fuel-cell trucks and buses on the road today, with Chinese manufacturers leading the way. The development of new low-carbon growth sectors provides an opportunity to enhance private participation and innovation, both to complement and in competition with state-owned enterprises that have historically dominated the energy sector.

As China decarbonises, domestic demand can galvanise the commercial development and deployment of low-carbon fuels and technologies. This will not just meet domestic demand, but also position China as a global leader in the provision of low-carbon goods and services.

China already leads the world in the manufacture of batteries, solar photovoltaic and electric vehicles (battery and fuel cell), and is second only to Europe in electrolyser manufacturing capacity.

Looking ahead, China's large and growing shipping and aviation sectors will require low-carbon fuels and new propulsion technologies to decarbonise. This will create new opportunities in areas such as the manufacture of aircraft and ship engines powered by low-carbon energy.

China also holds significant reserves of minerals and metals - such as lithium, cobalt and nickel - which are used to produce clean energy technologies, as well as a significant share of the global processing and refining capacity for these minerals and metals today.

Demand for these materials is only likely to rise as the energy transition gathers pace. This will directly benefit the Chinese economy, as well as indirectly benefit its domestic low-carbon manufacturing industry.

China's heavy industries, which are reliant on coal, pose the most significant challenge to decarbonisation. While the share of heavy industry in China's economy is expected to decline, it is still likely to remain a significant source of energy demand in the decades to come.

Transitioning to the use of low-carbon energy sources in these industries – for example, steel produced using hydrogen, chemicals produced using bioenergy, and the application of CCUS to cement production – provides an opportunity for China to become an exporter of low-carbon industrial products and technology as well as low-carbon industrial know-how and expertise.

A thriving low-carbon industrial-economic ecosystem provides China with an alternative to deindustrialisation. This, in turn, could arguably allow China to make an even more significant contribution to global decarbonisation efforts. China could develop and commercialise new industrial processes and technologies and then make them available to less-developed countries to help them leapfrog the most emission-intensive stages of their economic development.

Social impact

In the long term, a net-zero emissions energy system will produce significant societal benefits. These include more efficient energy consumption and better environmental outcomes.

However, given the scale, scope and speed of change, the effects of this transition will not be equally felt across provinces, sectors, industries and people with different economic means. Real progress entails spreading out the economic, social and environmental benefits of the energy transition to all parts of society, while supporting those most negatively impacted by its effects.

For instance, a renewables-based electricity system is expected to become cost-competitive with current fossil-based electricity systems In the interim, however, energy prices could potentially be higher and more volatile. The transition will require large investments in renewables, flexibility and enhanced transmission and distribution networks, and in the technologies and fuels required to decarbonise hard-to-electrify sectors that will need time to become fully commercialised.

The impact of higher energy prices will disproportionately affect lower income groups, as they typically spend a higher share of their income on energy.

As highlighted in the previous sections, the transformation of China's energy system will also have significant regional or provincial effects, as well as sectoral impact. This will in turn create social disruptions and dislocations.

BOX 6: THE COAL TRANSITION

The transition away from coal – by far the most emissions-intensive fossil fuel – is a key condition for China to achieve its objective to be carbon neutral by 2060.

As the cost of renewables like solar and wind decline, they become increasingly cost-competitive with coal-fired generation. This trend is expected to continue, with the system costs (generation and flexibility) of a low-carbon electricity system in China in 2050 estimated to be lower than that of today's fossil-based electricity system. Combined with investments in low-carbon energy infrastructure, a renewables-based power system could result in lower electricity prices compared to the current coal-dominated system. This trend will be accelerated by carbon pricing policies, such as through the national energy trading scheme (ETS), that will further level the playing field between coal-fired generation and lower-carbon generation like natural gas and renewables.

Apart from electricity, heavy industry is the major coal consumer in China today. While there are significant opportunities to improve the energy and emissions efficiency of coal, the sector will substantially transition away from it in the long term. As the national ETS is expanded to cover emission-intensive industries, the rising carbon price will incentivise switching away from coal to low-carbon fuels such as hydrogen and advanced biofuels. In industrial uses where it is most difficult and expensive to displace coal, CCUS will have a role to play, supported by the carbon price.

China's coal industry, in particular, is likely to experience substantial social impact with expected plant closures as the country transitions.

Coal is by far the single largest energy source in China's energy mix today, and its mining sector currently employs about 2.6 million people.[30] This number is significantly higher when taking into account all the workers across the entire coal value chain and its associated industries and businesses. With entire local economies, communities and livelihoods oriented around coal production in some regions, local governments will need to take early action to ensure a smooth transition.

Retraining and reskilling workers will be key to helping them find new jobs and livelihoods, especially in growth sectors such as renewable energy, rare earth and metals mining, CCUS and bioenergy. Similarly, long-term investment in skills and capabilities will be required for low-carbon heavy industries and advanced manufacturing. For workers unable or unwilling to take up new low-carbon job opportunities, wider social and welfare support will be needed to manage redundancies and early retirements, while ensuring social stability. Other countries have effectively managed coal transitions in the past. Box 8 outlines some lessons from their experiences that may be relevant for China.

Beyond any potential social disruptions, the energy transition is an excellent opportunity to promote high-quality economic, ecological and social development.

According to the Intergovernmental Panel on Climate Change's 1.5°C report, climate mitigation actions have significant synergies with the 17 Sustainable Development Goals[31] for 2030.[32] China has made enormous strides over the past few decades, in poverty reduction and in raising living standards. Less than 1% of the population was estimated to be living under the poverty line[33] in 2020, compared to about 50% at the end of the last century. Universal access to electricity was achieved in 2014.

Even as the world decarbonises, it will be important to ensure communities are resilient to locked-in climate impacts, such as rising sea levels and extreme weather conditions and events, whose negative effects are often disproportionately felt by vulnerable and disadvantaged communities.

The energy transition offers the opportunity for China to build on its economic and social development gains while making progress in the energy transition. It can do so by ensuring vulnerable and underserved communities have

> "Less than 1% of the population was estimated to be living under the poverty line in 2020, compared to about 50% at the end of the last century."

access to affordable and reliable energy and are resilient to locked-in climate impacts, while helping them to benefit from climate mitigation and adaptation opportunities presented by the energy transition.

International impact

China's actions to achieve carbon neutrality are not just critical to meeting the goals of the Paris Agreement, they will also have wide-ranging implications for global markets and the world's journey to net zero.

As China deploys low-carbon technologies and fuels, the scale of that demand will help accelerate cost declines in close-to-market technologies and fuels. It will also accelerate progress towards demonstrating and commercialising those fuels and technologies that are further away from the market.

In turn, this will create technology spillover benefits for the region and the world, with the greater availability and lower cost of low-carbon technologies and fuels driving their increased adoption. Given the existing strong trade links between China and other countries in the region, the decarbonisation benefits could be significant. For example, more than half of China's solar photovoltaic and lithium battery exports today are made to other countries in the Asia-Pacific region.

As China transitions from a fossil-based to a low-carbon energy system, it will affect the supply chains of both. For example, as China's coal demand declines, it will put downward pressure on coal prices and potentially turn China from a net importer to a net exporter of coal. This could drive greater take-up of coal outside China, which represents a potential negative spillover in the absence of containment measures.

From a low-carbon energy perspective, the global supply chain for rare earth elements will also be affected by China's energy system transformation. China currently accounts for a third of global reserves of rare earth elements[34] as well as 60% of global production[35] and 60% of exports.[36] How it balances supply between global and domestic markets, especially as domestic demand rises, will be critical for global supply chain stability. Developing global reserves of rare earth elements, as well as building and diversifying supply chains, will be important for China and the rest of the world to successfully decarbonise.

Finance can play an important role in maximising the positive international impact of China's energy transition, while minimising the negative effects. China's Belt and Road Initiative (BRI) is a prime example of how Beijing is using investments to support climate-sustainable development overseas. The BRI portfolio, which amounted to about $265 billion in predominantly fossil-based energy and electric power projects worldwide between 2013 and 2018[37], is shifting to a focus on renewables. In 2020, investments in solar, wind and hydrogen-based projects accounted for most (57%) of China's overseas energy portfolio for the first time.[38]

This follows China's pledge in 2017 that BRI projects would be used to promote the Paris Agreement and the 2030 Sustainable Development Goals. Ahead of COP26, China pledged to stop financing new coal-fired power plants outside China. This alignment offers two benefits. It:

- helps to accelerate the global energy transition and promote climate-sustainable development, particularly in developing and emerging markets; and
- expands overseas markets for Chinese low-carbon products, technologies and expertise.

COMPREHENSIVE, COHERENT AND CREDIBLE POLICY FRAMEWORKS

Policy has a fundamental role in driving the energy transition to net zero. It can:

- speed up technology development, commercialisation and diffusion;
- improve the economics of low-carbon goods and services;
- help get the necessary infrastructure built;
- manage the wider economic and social impacts of the transition; and
- knit together sectoral coalitions for action to deliver the required pace of change.

Shell's global Energy Transformation Scenarios – **Waves**, **Islands** and **Sky 1.5** – identify the "speed of the transition" as the determining factor of whether the goals of the Paris Agreement will be met or not. All three scenarios make progress in the energy transition, relying on a similar set of low-carbon technologies and fuels to decarbonise. But the key difference between the three lies in the speed of deployment: **Sky 1.5**, which is driven by the three accelerators of alignment, smart policy and pioneer leaders, is the only one fast enough to meet the stretch 1.5°C goal of the Paris Agreement. In this context, public policy has a fundamental role to play.

Making the transition will require taking a comprehensive and economy-wide policy approach, such as setting binding national targets, a robust carbon price, as well as necessary investments to electrify the economy.

This holistic policy approach, however, will need to be supported by coherent sector-specific policies to accelerate the energy

"Finance can play an important role in maximising the positive international impact of China's energy transition, while minimising the negative effects."

transition, particularly in the hardest-to-abate sectors. Potential technology, fuel and infrastructure solutions vary across these sectors, and are still some distance from commercialisation today.

Finally, making progress at pace will require addressing the societal frictions and dislocations that the energy transition creates.

Along with energy and climate policies, credible social policies will be required to ensure the energy transition delivers better economic, social and environmental outcomes for all, thus creating broad societal support for tackling climate change. Box 7 sets out the essential elements of an effective energy transition policy framework.

BOX 7: ELEMENTS OF AN EFFECTIVE POLICY FRAMEWORK

To drive economy-wide change

1. **Set binding decarbonisation targets and a clear trajectory for achieving them**, in order to reduce policy uncertainty and incentivise necessary investments over time.
2. **Ramp up carbon pricing over time** to reallocate resources towards low-carbon sources; improve business and household energy efficiency; incentivise low-carbon choices as they become available; and bridge any remaining cost difference for low-carbon fuels and technologies.
3. **Rewire the economy with low-carbon electricity** through investments in low-carbon generation and flexibility; optimisation of system performance; extension and expansion of transmission and distribution networks; and electrification infrastructure such as EV charging networks.

To accelerate sectoral transitions

4. **Encourage better coordination within sectoral value chains** for hard-to-electrify sectors in transport (aviation, shipping and heavy-duty road freight) and industry (steel, cement and chemicals).
5. **Provide time-limited fiscal and financial incentives** to drive investment in and commercialisation of low-carbon molecules, such as hydrogen and advanced biofuels and biomass.
6. **Create initial markets or demand for these low-carbon fuels** through various means, such as sectoral carbon pricing, emission performance standards and policy mandates.
7. **Support infrastructure planning and investment** to enable the commercial adoption of low-carbon molecules.
8. **Establish governance for carbon removals** to incentivise investment in CCUS and BECCS in a way that does not undermine broader mitigation action or the shift to low-carbon energy.

To create societal support

9. **Create clear and predictable policies** that keep overall macroeconomic costs of the transition manageable.
10. **Adopt fair and equitable policies** that mitigate regional, sectoral and distributional impacts of the transition.
11. **Establish transparent and inclusive policies** that encourage wide societal innovation and participation in change.

China has a comprehensive strategic and policy governance system, which consists of overarching industrial policy for the medium and long terms and five-year plans for the shorter term. These provide a strong foundation for delivering China's energy and climate objectives, offering policy continuity and stability critical for transforming the energy system – and the economy – over the next 40 years.

The 14th Five-Year Plan sets out key areas for action in the first half of this decade to put China on a trajectory to be carbon neutral by 2060. It sets out strategic objectives for economic and social development for the 2021-25 period, building on the efforts of previous five-year plans to improve energy and environmental outcomes. For example, gas market liberalisation measures were set out in the previous five-year plans to displace coal and increase the share of cleaner natural gas in China's energy system to 10% by 2020 and 15% by 2030.[39]

Making progress towards an ecological civilisation is one of the six overarching economic and social development goals in the 14th Five-Year Plan.[40] In this context, the plan sets out some key energy and climate indicators:

- a reduction in energy consumption per unit of GDP (or energy intensity) of 13.5% between 2021 and 2025;
- a reduction in CO_2 emissions per unit of GDP (or CO_2 emissions intensity) of 18% between 2021 and 2025;
- an increase in forest coverage from 23.4% in 2020 to 24.1% in 2025; and
- an increase in total energy production to more than 4.6 billion tonnes of coal equivalent (or about 135 EJ) from fossil (coal, petroleum, natural gas) and non-fossil energy.

While all four energy- and climate-related indicators are binding in nature because they serve as political key performance indicators, the 14th Five-Year Plan also proposes an increase in the share of non-fossil energy to 20% by 2025, compared to 12% in 2019.

A combination of ambition and action will need to be ramped up in a sustained and systematic way throughout subsequent five-year plans. However, the process creates a degree of policy stability and certainty that helps incentivise the necessary actions and investments needed and keep the overall costs of transition to a minimum.

A transformative role for industrial policy

Making progress towards carbon neutrality and fully embracing the opportunities it creates will require an integrated and ambitious industrial policy. This will include actions to:

- promote the development of new industries, such as the manufacture of solar panels, wind turbines, batteries and hydrogen electrolysers;
- develop low-carbon industrial processes and transform heavy industry, such as through green steel produced using hydrogen, the application of CCUS to cement production facilities, and chemicals produced from bioenergy;
- develop supplies of and supply chains for low-carbon energies such as hydrogen and bioenergy; and
- develop low-carbon and digital consumer and business solutions.

The 14th Five-Year Plan has set a clear objective to develop strategic emerging sectors[41] as well as key areas for innovation to support these future growth industries.[42] This can be supported using industrial policy to set the longer-term direction and speed up transformation of the energy system.

For example, in 2020, China accounted for 25% of global public spending on energy R&D and 15% of low-carbon energy R&D.[43] In the private sector, Chinese start-ups are estimated to have received 35% of global energy-related venture capital since 2017.

An industrial strategy that provides additional clarity and focus on low-carbon energy policy priorities can better direct China's considerable public R&D resources, as well as stimulate private investment – both domestic and foreign.

With concerted industrial policy action, China can position itself as the global market leader in new energy fuels, technologies and expertise.

Unprecedented policy vision, alignment and coordination

A smooth and orderly transition to carbon neutrality will require unprecedented levels of coordination and collaboration across all levels of policymaking – national, provincial, municipal and city.

In particular, the widespread electrification of the Chinese economy using low-carbon electricity is an essential element of the pathway to carbon neutrality. Achieving a reliable, affordable and low-carbon electricity system in the next 40 years will require coordinated planning and investment to expand and upgrade transmission and distribution networks. It will also need collaboration across provinces to optimise the electricity system.

The energy transition is more than a techno-economic process of transforming the energy system, it is also a social process of change. For instance, managing China's transition away from coal will require policy vision and consistency, such as by:

- integrating energy and climate policies with labour market policies to reskill and retrain workers;
- introducing education policies to develop new capabilities; and
- implementing wider social policies to manage inevitable redundancies and early retirements.

Box 8 sets out lessons from international experience of coal transitions.

"With concerted industrial policy action, China can position itself as the global market leader in new energy fuels, technologies and expertise."

BOX 8: LESSONS FROM INTERNATIONAL EXPERIENCE OF COAL TRANSITIONS

The challenge of managing the transition away from coal is not unique to China. Other countries such as Germany, Poland, the UK and USA have grappled with the issue, with varying degrees of success. Based on their experience, successfully managing the coal transition will require:

- **Building a social contract**: Climate science demands a rapid energy transition. But faster transitions threaten the capacity of local labour markets to replace jobs lost in coal. Trade unions have begun shifting from defensive support for coal towards a "just transition" approach, which secures workers' rights while transitioning to a green economy.

  Granted, this union support could still unravel once redundancies start to bite. But effective negotiations have been a powerful tool used by countries like Germany to manage industrial transitions in its western coal regions since the late 1960s.

- **Planning early for closures**: If transition planning is delayed until mass redundancies are on the horizon, labour markets will not be able to cope with the large volume of displaced workers. Early planning for closures is starting to emerge at an industry and company level in some nations such as Australia, Germany and Italy. These plans include retraining, support for early retirement and the redeployment of workers.

  Site remediation is also an important way to restore the local environment, create community buy-in for the transition, and create semi-skilled and low-skilled jobs at the most critical time of the transition.

- **Diversifying the regional economy**: As coal-related jobs decline, some categories of employment can be transferred to other sectors such as renewables and CCUS. Development of bio-resources could be another way of diversifying the regional economy.

  However, market restructuring alone will not deliver a just transition. Some coal regions see little prospect for developing large-scale renewables, CCUS or bioenergy. This means workers will rarely transfer seamlessly to new jobs without having to move away from home. Moreover, as many of the new opportunities are likely to be in the construction phase, existing employment will be replaced by a higher volume of temporary jobs.

- **Establishing comprehensive policy frameworks, funds and authority to facilitate a just transition**: It is essential that policies do not simply incentivise or support low-carbon energy, but also manage the socio-economic impacts of the transition.

  Specialist funds are being established to oversee, develop and implement coal transition programmes. The European Commission, through its initiative for coal and carbon-intensive regions in transition, is investing funds in 13 coal regions. Germany has recommended a funding package of €40 billion to support coal regions; and Spain has established a €250 million fund, which includes support for workers, economic diversification and environmental restoration.

SECTORAL COALITIONS FOR ACTION

Accelerating the speed of transition to be consistent with a scenario like **Sky 1.5** will require unprecedented collaboration to create a virtuous cycle of change between the following key groups:

- governments whose role is to create an enabling policy framework;
- businesses that innovate to develop new low-carbon products and services, as well as business models to support them; and
- consumers that demand low-carbon products and solutions.

Businesses which supply energy must come together with businesses in sectors that use energy: from shipping to finance, aviation to chemicals, steel to cement. The entire ecosystem in each sector of the economy will need to work together to pursue net-zero emission pathways.

This is particularly true for the harder-to-abate sectors in transport and heavy industry. Unlike power generation and passenger road transport, the decarbonisation journey in harder-to-abate sectors is just starting. Not only are these sectors more difficult to electrify due to the need for thermal heat and energy dense fuels, their potential solutions also vary sector by sector.

Speeding up the pace of transition will require concurrent investments in all stages of the value chain. Taking the example of the steel sector: equipment manufacturers need to invest in technology to run on low-carbon energy such as hydrogen; steel plant owners need to upgrade their production processes; infrastructure owners need to develop the necessary hydrogen transport and storage facilities; and fuel suppliers need to develop adequate low-carbon hydrogen supply. This is a departure from the sequential way that new technologies have typically been developed, deployed and diffused.

While individual sectors are best positioned to identify pathways to net-zero emissions, as well as the investments required to support them, governments alone have the legitimacy, mandate and policy levers to remove obstacles to progress. Hence, government policy is indispensable to ensure such pathways are widely supported.

In China, there is a strong link between government and state-owned enterprises (SOEs), with the 14th Five-Year Plan explicitly requiring SOEs to promote the deployment of new energy-saving, low-carbon and environmentally friendly technologies.

Chinese companies – both public and private – are starting to take action to reduce emissions. For example, Sinopec, China's second-largest energy SOE, announced its intention in 2021 to become carbon neutral by 2050, pivoting its portfolio on natural gas in the short term and green hydrogen in the long term. Baosteel, the country's largest steel producer, has pledged to reach net-zero emissions by 2050, focusing on hydrogen-based steel production.

Sectoral coalitions for action will be essential to accelerate progress during this decade in the harder-to-abate sectors, particularly in capital-intensive heavy industries. These coalitions need to include private and public companies across the energy supply and end-use ecosystem and be supported by government.

“Businesses which supply energy must come together with businesses in sectors that use energy: from shipping to finance, aviation to chemicals, steel to cement.”

CITIES AS INCUBATORS OF CHANGE

Urbanisation trends mean that cities are crucial to the success of a country's energy transition. They are a microcosm of the wider societal energy transition, illustrating the opportunities and challenges it presents. Making progress at pace requires:

- cross-boundary collaboration across energy, environmental, mobility and other urban services;
- non-traditional partners including citizens, consumers, governments at various levels, and a variety of private sector operators that provide urban services; and
- new ways of partnering and convening to deliver integrated urban services, including energy.

Between 2000 and 2020, the share of China's population living in cities jumped from 36% to more than 60%. This proportion is expected to exceed 75% by 2050. With so much of the country's population, industry and energy demand located in urban areas, decarbonisation in the cities will be key to achieving the goal of carbon neutrality by 2060.

> Urbanisation trends mean that cities are crucial to the success of a country's energy transition. They are a microcosm of the wider societal energy transition, illustrating the opportunities and challenges it presents.

Cities are already taking the lead. More than 60 cities have committed to achieving peak carbon emissions before 2025 – five years ahead of the national target. Shanghai has pledged to peak emissions by 2025; Beijing is aiming for emissions to peak between 2021-23 followed by a steady decline.

As part of their commitment to peak emissions, 25 cities have set renewable energy targets as well as policies that cover 321 million people, or 38% of the urban population of China.[44]

Cities are also taking the lead in the deployment of fuel cell electric vehicles and buses, as part of wider provincial strategies for developing a hydrogen economy. Shenzhen, Beijing and Guangzhou were the three leading cities in the world for passenger EV sales in 2019. In 2018, Guangzhou converted its entire fleet of 11,220 city buses to electric vehicles, in collaboration with a wide spectrum of partners.

Cities like Guangzhou, Shanghai and Shenzhen, which are hubs for industrial activity as well as hosts to some of the busiest airports and ports in the world, have the potential to drive significant emission reductions in some of the hardest-to-abate sectors. Industrial zones, with their relatively concentrated infrastructure and high consumption of energy, are fertile ground for city governments to encourage vibrant, low-carbon ecosystems with integrated solutions.

Seizing these opportunities will produce dual benefits for cities. Not only will cities be able to make a significant contribution to China's 2060 carbon neutrality goal but by acting as incubators and demonstrators of new technologies and collaborative ways of working, they will also create new economic opportunities for their residents.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CONCLUDING REMARKS

Building a net-zero energy system in China by 2060 is a hugely challenging task, not least because China's economy – and energy demand – continues to grow, even as the country seeks to decarbonise.

This scenario sketch sets out a unique pathway for achieving net-zero emissions in the energy system by 2060, based on our best assessment of the technical and economic potential of various low-carbon technologies and fuels. Variations of this pathway are possible, depending on societal and policy preferences, but the underlying technology and fuel options remain the same.

Key elements of the carbon-neutral energy system presented in this sketch are:

- generation of electricity for end-use increases threefold from 20 EJ in 2020 to more than 60 EJ in 2060. Its share of final energy increases 2.5 times from 23% today to almost 60% in 2060;

ACTIONS TO MAKE PROGRESS THIS DECADE

1. **Invest in reliable, renewables-based electricity networks.**
2. **Position China as the market leader in low-carbon manufacturing.**
3. **Pilot technologies that transform heavy industry through hydrogen, bioenergy and CCUS.**
4. **Begin an orderly transition out of coal.**
5. **Accelerate action through integrated policies, sectoral coalitions and cities as incubators of change.**

- electricity for hydrogen production adds another 25% to electricity demand by 2060. The overall electricity system (for end-use and hydrogen production) is almost four times today's size;
- the electricity mix shifts from around 65% generated by fossil fuels to one dominated by renewables - 80% of which is generated by wind and solar - by 2060. Any remaining fossil fuels in power generation are fitted with CCUS;
- the share of hydrogen rises from negligible levels today to about 16% of final energy consumption in 2060, mainly due to its use as a fuel for industry and long-distance transport;
- the use of bio-resources (commercial biomass and liquid biofuels) rises from around 2 EJ today to almost 17 EJ in 2060. Use of residential biomass declines, while that of commercial biomass (primarily in industry and power generation, including CCS) increases substantially;
- energy efficiency continues to improve, especially in industry. This is achieved through integrated and low-carbon urban infrastructure and electrification. Energy intensity of the economy roughly halves between 2020 and 2060;
- total final consumption of energy is reduced by about 39% by 2060 compared to business-as-usual, thanks to significant energy efficiency gains;
- a carbon price (explicit and/or implicit) rises to about CNY 300/tCO_2 in 2030 and up to CNY 1,300/tCO_2 by 2060; and
- carbon removals through CCUS play a significant role in achieving net-zero emissions in China's energy sector by 2060, reaching more than 1.3 Gt of CO_2 annually in 2060. This includes 0.6 Gt of negative CO_2 emissions from BECCS.

By transforming its energy system, China has an opportunity to become a prosperous pioneer in deploying clean energy technologies and fuels. It is also well placed to become a global leader in new energy technologies and solutions that can help to address both domestic and international challenges.

Making progress will require concerted actions by business and government to seize opportunities and manage impacts in ways that maximise benefits for society. This, in turn, will spur support and enthusiasm among consumers and citizens for further progress in China's closely watched energy transition.

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GLOSSARY

Belt and Road Initiative	The Belt and Road Initiative, known in Chinese and formerly in English as One Belt One Road, is a global infrastructure development strategy adopted by the Chinese government in 2013 to invest in nearly 70 countries and international organisations.
Bioenergy with carbon capture and storage (BECCS)	Bioenergy with carbon capture and storage (BECCS) is the process of extracting bioenergy from biomass and capturing and storing the carbon, removing it from the atmosphere.
Carbon capture, utilisation and storage (CCUS)	CCUS technologies involve the capture of carbon dioxide (CO_2) from fuel combustion or industrial processes.
Emission trading schemes (ETS)	The EU Emissions Trading System (EU ETS) is a cap-and-trade style mechanism that covers all large point sources of emissions (mainly thermal power stations and industrial facilities) across all 27 countries of the EU.
High-quality growth	High-quality growth in Chinese policy is environmentally and socially sustainable economic growth that goes beyond the narrower definition of GDP.
International Energy Agency (IEA)	The International Energy Agency is a Paris-based autonomous intergovernmental organisation.
Nature-based solutions	Nature-based solutions provide natural carbon sequestration by protecting or developing natural ecosystems, such as forests, grasslands and wetlands.
Shell's Sky 1.5 scenario	An energy scenario that describes a world which has achieved the stretch goal of the Paris Agreement to limit global warming to below 1.5 degrees Celsius this century.
Sustainable Development Goals (SDGs)	A set of 17 global goals adopted by the United Nations to "end poverty, protect the planet and ensure prosperity for all".
The 3060 targets	China's target to achieve a carbon emissions peak by 2030 and carbon neutrality by 2060.

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LEGAL DISCLAIMER

This scenario starts with data from Shell's **Sky** scenario. In developing this scenario, we have assumed that China's energy system reaches net-zero CO_2 by 2060, consistent with President Xi Jinping's statement to the United Nations General Assembly in September 2020. We then worked backwards to see how this could occur. Of course, there are many possible paths for China to travel to a net-zero CO_2 energy system, but this is what we believe to be a technically possible path while maintaining a growing Chinese economy. While this scenario is more aggressive in its goal and assumptions than our **Sky** scenario, we believe, while extremely challenging it is still today technically possible. However, we believe the window for success is quickly closing and without significant action it may take longer for China to achieve a net-zero CO_2 energy system.

Shell scenarios, including this scenario, should not be confused with Shell strategy or business plan. When developing Shell's strategy, our scenarios are only one variable among many that we consider. Ultimately, whether society meets its goals to decarbonise, is not within Shell's control. While we intend to travel this journey in step with society, only governments can create the framework for success.

Shell's operating plan, outlook and budgets are forecasted for a 10-year period and are updated every year. They reflect the current economic environment and what we can reasonably expect to see over the next 10 years. Accordingly, Shell's operating plans, outlooks, budgets and pricing assumptions do not reflect our net-zero emissions target. In the future, as society moves towards net-zero emissions, we expect Shell's operating plans, outlooks, budgets and pricing assumptions to reflect this movement.

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