# China's net-zero plans

## Policy brief on near-term policy challenges & Australia-China links in decarbonization

Prepared by Tuyu Zhou, Hongzhang Xu, Jorrit Gosens, and Frank Jotzo

Draft version of 10 March 2022 -- Comments welcome

*This project was supported by the National Foundation for Australia-China Relations*

Crawford School of Public Policy, College of the Asia-Pacific

+61 2 6125 0559

jorrit.gosens@anu.edu.au

The Australian National University

Canberra ACT 2600 Australia

www.anu.edu.au

# Table of Contents

# 1. Introduction

Over the last two years, both Australia and China have joined a growing club of countries with net-zero emissions targets. Australia has pledged to get to net-zero emissions by 2050, and China will do so by 2060, with an interim target of peaking emission before 2030.

Beyond these headline strategies, much details on the trajectory towards this final target, and the specific policy instruments used remain to be worked out. For China, a key question will be how much of the effort to decarbonize will be done over the near-term, in an effort to limit the level at which emissions peak, and to bring the moment that emission peak to well before 2030. China is currently in a key policy design cycle, as it is starting to roll out strategies for its 14th Five-year Plan period (2021-2025). Limited details were included in its headline plan for economic development; sectoral plans for energy, subsectors such as specific energy sources, steel making, and more specific guidance on emissions trajectories and distribution of decarbonisation efforts over different provinces and different sectors, are all still expected to be published throughout 2022.

What is clear, is that while national low-carbon transitions will differ, Australia's and China's low-carbon transitions are deeply linked through their systems of energy and resource production and use. Low-carbon transitions open opportunities to establish new energy, resource and processing industries in Australia, on the basis of natural resource endowments.

This policy brief aims to provide a general overview to Australian business, governments and other stakeholders, of progress and plans in China's low-carbon transition. It provides description, analysis, and outlook based on currently published policies. It will be updated with the latest insights as new policy documents come out over the rest of the year.

This policy brief was developed by researchers at the Australian Centre on China in the World (CiW) at the ANU, with financial support from the National Foundation for Australia-China Relations.

# 2. Chinese climate policy achievements to date

## 2.1 Policy priorities in the 11th to 13th Five-Year Plan periods

### 11th FYP (2006-2010)

The 11th Five-Year Plan (FYP) for the Development of the Coal Industry, formulated in 2005, proposed to control the growth of coal production and consumption, with coal production planned to be controlled at 2.60 billion tonnes st coal eq in 2010, although production actually reached 3.43 billion tonnes st coal eq, this figure was corrected from 3.24 billion tons to 3.43 billion tons in the 13th Five-Year Plan for coal(NDRC & NEA, 2016a; NDRC, 2012a). Further policies during the 11thst Five-Year Plan were mainly focused on the demand side of energy. These policies include a range of policies to promote energy efficiency retrofits for users such as households and businesses, and to promote low carbon lifestyles for different groups of people. For example, through the State Council of China, Central Civilization Office and All-China Women's Federation, a household energy saving campaign targeting women was launched (All-China Women's Federation, Central Civilization Office, & NDRC, 2010). Meanwhile, financial subsidies were provided to enterprises to support the promotion of energy-efficient air conditioners (Ministry of Finance & NDRC, 2010), and five cities were selected for pilot subsidies for new energy vehicles based on the car industry base and the purchasing power of the population (MF, Ministry of Science and Technology, Ministry of Industry and Information Technology, & NDRC, 2010). In addition, the Chinese government introduced policies to deal with tight electricity supply and power demand-side management methods (NDRC, et al., 2010), and supported the development of the hydropower, photovoltaic solar and wind power industries through initial renewable energy feed-in-tariff subsidies (NDRC & State Electricity regulatory Commission, 2010). By the end of the 11th FYP period, installations of wind power stood at 31 GW, those of solar PV at just 800 MW (NDRC, 2012b).

### 12th FYP (2011-2015)

In response to the huge growth in energy demand over the 11th FYP period, the Chinese central government implemented a series of policies to aid the transition to clean energy. This included the first targets for installed non-fossil power generation capacity, of 30% of by 2015 (State Council, 2013).

For individual technologies, targets were set at 100 GW of wind, 21 GW of solar, and 13 GW of biomass power generation capacity. China's energy consumption continued to grow during the 12th Five-Year Plan period (2011-2015), although the effects of coal management have not yet been significant, and the Chinese government has released a series of energy efficiency plans and renewable energy support schemes to drive a cleaner transition in its energy use (NDRC, 2013). Due to the shortcomings of the 11th Five-Year Plan in achieving its objectives, the 12th Five-Year Plan began with a radical restructuring of the single command and control policy, introducing low-carbon, green and sustainable development as well as market incentives. These policies include an emphasis on dual control of energy consumption and energy intensity include carrying out actions to reduce coal consumption, expanding the natural gas consumption market, implementing electrical energy substitution projects, and proposing 'efforts to resolve and prevent overcapacity', as well as the upgrading of energy-intensive industries such as steel and cement.

At the same time, preferential policies for the coal sector remained in place, driven by state-owned enterprises and supported by local governments, and the effects of severe air pollution became apparent during this period and became particularly severe in 2013 and 2014 (Ahlers & Shen, 2018; NDRC & CNREC, 2018; Su et al., 2018; Y. Xu & Salem, 2021a) . As China's leadership and the public became increasingly concerned about the environment and sustainable development, reducing coal consumption gradually became an option for reducing air pollution. In response, the State Council released the Air Pollution Action Plan (2013-2017), which set specific targets for improving air quality in three major economic regions, the Beijing-Tianjin-Hebei region, the Yangtze River Delta and the Pearl River Delta (State Council, 2013). Through the energy revolution launched in 2014 and the emphasis on more sustainable economic development and adapting to the new normal of low economic growth, energy-related air pollution has become an important driver for restructuring the energy sector (NDRC & CNREC, 2017). To achieve this goal, China has invested in renewable energy policies with significant financial subsidies and administrative support, notably the establishment of the Renewable Energy Foundation to provide subsidies for renewable energy feed-in tariffs, and a ten-year strategy launched at the end of the 12th Five-Year Plan, "Made in China 2025", which emphasises the promotion of innovation in renewable energy, including solar PV and wind in the power sector (Heggelund, 2021). A study that examined the drivers of change in China's energy consumption during the 12th Five-Year Plan period found that within the final demand category, China's energy structure was mainly contributed by investment and household consumption (Yan & Su, 2020). China overdelivered on its renewable energy targets, with 131 GW of wind and 43 GW of solar PV by the end of the $12^{th}$ FYP period, whilst biomass power generation grew of 11 GW, just short of its original target (Table 2) (NDRC, 2016a).

## $13^{th}$ FYP (2016-2020)

In the $13^{th}$ Five-Year Plan period, China's natural gas consumption increased, while oil consumption decreases significantly compared to the $12^{th}$ Five-Year Plan period. Coal production and consumption started to plateau, and the share of coal in total energy consumption decreased by 7% in 2020. The gap between rural and urban energy consumption has been further narrowed by the promotion of photovoltaic poverty alleviation projects. These results are attributed to the addition of specific and quantifiable policy targets during the $13^{th}$ Five-Year Plan period including a binding coal consumption target of 58% of coal consumption for the first time, and a wide range of other energy supply-side policies including policy instruments to reduce $CO_2$ emissions from coal-based energy technologies, a portfolio of policy instruments to encourage renewable energy technologies and the development of Clean Development Mechanism (CDM) projects, as well as providing a pilot program to reduce $CO_2$ emissions from coal-based energy technologies with a focus on solar PV and wind power (MF, NDRC, & NEA, 2017). The Tradable Green Certificate (TGC), piloted by solar PV and wind power, is also available to electricity consumers to increase customer-side renewable energy demand(Yang et al., 2021).

Throughout the $13^{th}$ Five-Year Plan period (2016-2020), a portfolio of policy tools was implemented to support comprehensive coverage of various renewable energy technologies. Most of these policy instruments are based on the resources and economic development established in their different regions, using the financial, administrative and regulatory resources at the disposal of governments to address the positive externalities of renewable energy deployment in terms of reducing environmental pollution and driving industrial development(Y. Li & Taghizadeh-Hesary, 2022a). Feed-in tariffs (FIT) and renewable energy portfolio standards (RPS) are the most common policies have been widely used. With higher expected output, profits and lower market prices than the RPS policy, the FIT is suitable for the early stages of the renewable energy industry. As the wind and PV industries significantly developed, the prices of these technologies came down rapidly as well, the FIT is no longer a desirable renewable energy incentive for China. While the FIT increases the financial burden of government subsidies for renewable energy, and the FIT and RPS should be used in combination (Yang et al., 2021). In response, the pricing department of the NDRC started to regularly decrease the FIT for both technologies. In April 2019, the NDRC published a notice ordering all distributed and centralized PV plants to participate in competitive bidding, except for poverty alleviation and household distributed plants (NDRC, 2019). In May of 2019, as similar notice was published for wind, effective by the end of 2020 (NDRC, 2019). This means that the renewable energy FIT policy is being phased out, and renewable power generators will have to compete with coal-fired power on price. Many other policy instruments play a key role in guiding the electricity market, planning provincial renewable energy quotas, and setting quotas for each type of renewable energy (Lei et al., 2018). The state-owned enterprises dominated Chinese electricity market presents challenges for Chinese regulators in designing mechanisms and cost payments for how costs are shared among state-owned banks, other state-owned enterprises, and different categories of electricity consumers (J. Lin et al., 2019).

## 2.2 Targets and achievements in the 11th to 14th Five-Year Plan periods

**Table 1. Key energy structure targets and achievements for the 11th-14th FYP**

| Index | unit | 11th FYP (2006-2010) | | 12th FYP (2011-2015) | | 13th FYP (2016-2020) | | 14th FYP (2021-2025) |
|---|---|---|---|---|---|---|---|---|
| | | Target | Actual | Target | Actual | Target | Actual | Target (projected) |
| Share of non-fossil power generation capacity | % | -- | 26.8 | >30 | 35 | >39 | 44.5 | (51)[b] |
| Share of non-fossil power generation | % | >9 | 9.4 | >20 | 27 | >31 | 34 | (40)[b] |
| Share of non-fossil energy consumption | % | >8.1 | 8.6 | >11.4 | 12 | >15 | 15.8 | 20[a] |
| Share of natural gas consumption | % | >5.3 | 4.0 | >7.5 | 5.9 | >10 | 8.5 | (11.5)[b] |
| Share of coal consumption | % | <66.1 | 69.2 | <65 | 63.8 | <58 | 56.8 | (48)[b] |
| Share of total coal consumption used in power generation | % | -- | -- | -- | 49 | <55 | 47 | (52.3)[b] |
| Electrification rate of end-use energy | % | -- | -- | -- | -- | >27 | 27 | (31)[b] |
| Energy security rate | % | -- | -- | >79.6 | 84 | >80 | 82 | (>81)[b] |

Source: (NDRC, 2007; NDRC, 2013; NDRC, 2016; CEC, 2022). Note: a) official target announced in 14th FYP (State Council, 2021c); b) likely target as projected by (Yang & Chen, 2021).

**Table 2. Key energy consumption and production targets and achievements, 11th-14th FYP**

| Index | unit | 11th FYP (2006-2010) | | 12th FYP (2011-2015) | | 13th FYP (2016-2020) | | 14th FYP (2021-2025) |
|---|---|---|---|---|---|---|---|---|
| | | Target | Actual | Target | Actual | Target | Actual | Target (projected) |
| Decline in energy intensity of per unit of GDP | % | -- | -- | 16 | 18.5 | 15 | -- | (14.7)[d] |
| Non-fossil fuels share | % | -- | -- | 11.4 | 12.1 | 15 | 15.8 | (20)[d] |
| Decline of CO2 intensity per unit of GDP | % | -- | -- | 17 | 21.7 | 18 | 18.8 | (19)[d] |
| Total installed power gen. capacity | MW | -- | 970 | 1,500 | 1,530 | 2,000 | 2,200 | (3,000)[c] |
| Total energy consumption | Mt standard coal eq. | -- | 3,610 | 4,000 | 4,300 | <5,000 | 4,980 | (5,500)[c] |
| Total CO2 emissions | Billion ton | -- | -- | -- | 9.29 | -- | 9.9 | (10.4)[d] |
| Total coal consumption | Mt coal (orig. weight) | 1,785 | 2,498 | 3,900 | 3,960 | 4,100 | 4,094 | (3,820)[c] |
| Electricity consumption | TWh | -- | 4,200 | 6,150 | 5,690 | 7,200 | 7,510 | (9,350-9,630)[c] |
| Primary energy production capacity | Mt st. coal eq. | 2,446 | 2,970 | 3,660 | 3,620 | 4,000 | 4,080 | (4,460)[c] |
| Coal production | Mt | 2,600 | 3,430 | 4,100 | 3,750 | 3,900 | 3,843 | -- |
| Natural gas production | Billion $m^3$ | 92 | 95.8 | 156 | 135 | 220 | 205 | -- |
| Non-fossil energy Production | Mt st. coal eq. | 220 | 284 | 470 | 491 | 560 | 764 | -- |
| Reduction in energy intensity per unit of GDP | % | -- | -- | 16 | 16 | 15 | 13.8 | (15)[c] |
| Hydro power | GW | -- | 216 | 260 | 319 | 340 | 370 | -- |
| Nuclear power | GW | -- | 10.8 | 40 | 27.2 | 88[a] | 49.9 | 70[b] |
| Wind power | GW | 12.6 | 29.6 | 100 | 131 | 210 | 282 | 1,200 GW by 2030[b] |
| Solar power | GW | 0.7 | 0.2 | 21 | 42.2 | 105 | 253 | |
| Biomass power | GW | -- | 1.7 | 13 | 11.3 | 15 | 14.7 | -- |
| Coal cons. for power generation | g st. coal-eq./kWh | 335 | 333 | 323 | 318 | <310 | 305.5 | (300)[b] |

Notes: a) including capacity operational and under construction; b) official targets, announced in 14th FYP (State Council, 2021c; NDRC & NEA, 2021); c) likely target as projected by (Yang & Chen, 2021); d) likely target as projected by (Institute of Climate Change and Sustainable Development of Tsinghua University, 2022).

# 3. 14th FYP policy and targets announced thus far

In September 2021 president Xi Jinping announced to the UN General Assembly that China would aim to have carbon emissions peak before 2030, and reduced to net-zero by 2060. The suggested trajectory to get to zero by 2060, is still the subject of debate. For the next decade, there is a range of ambition levels that would fit with these headline targets, including different level at which emissions would peak, and the year in which they would do so.

China is currently still drafting most of its energy plans for the 14$^{th}$ Five-Year Plan period, which runs from 2021 to 2025, but a number of targets has been announced in related policy documents. In October 2021, China submitted its updated Nationally Determined Contribution (NDC), required under the Paris agreement, with each NDC update requiring increasingly ambitious emissions reduction targets. In it, China reiterated peaking carbon emissions "before 2030", versus a previous commitment to peak emissions "around 2030 and making efforts to peak earlier". China also committed to lowering emissions per unit of GDP by more than 65% in 2030 (compared to 2005 levels), versus a previous commitment of reductions between 60 to 65%. China also pledged to increase its forest stock volume by 6 billion $m^3$ from the 2005 level, versus an earlier commitment of 4.5 billion $m^3$. The NDC also announced more ambitious increases, in the share of non-fossil energy in primary energy consumption, which was updated to "around 25%" by 2030, versus an earlier commitment of "around 20%", and an additional target of 1,200 GW of total installed capacity of wind and solar power by 2030.

In the 14th Five-Year Plan for economic development (National People's Congress of the P.R. China, 2022) and the 'outline of Vision 2035' (State Council, 2021b), additional interim goals were announced, of increasing the share of non-fossil energy to 20% by 2025, and to get to 70 GW of installed nuclear capacity, also by 2025.

Besides these domestic emission reduction efforts, Xi Jinping announced in September 2021 that China would no longer support new coal-fired power projects overseas (Yi, 2021).

It is expected that in the first half of 14$^{th}$ FYP period, China's high energy-consuming industries, such as heavy and chemical industries, will keep growing, and increase energy consumption (ICCSD, 2022). In the latter of the 14$^{th}$ FYP period, the expansion of these industries may be stopped, resulting in decreasing energy consumption (ICCSD, 2022). An important mechanism for emissions reduction, is a general shift away from heavy industry and towards high-tech manufacturing over the 14$^{th}$ FYP period (Xinhua Net, 2022; Xia, 2021). Projections are that non-fossil energy could maintain the 7% annual growth during the 14th FYP period, that the non-fossil share of primary energy consumption may reach roughly 20% in 2025, and that the share of coal will fall from 56.8% in 2020 to approximately 51% by 2025 (ICCSD, 2022). The NEA proposed in March 2021 that the proportion of installed renewable energy power plants would exceed 50% by the end of the 14$^{th}$ FYP Period (Xinhua News Agency, 2021). Based on these projections, $CO_2$ emissions per unit of GDP could drop by roughly 19% during the 14$^{th}$ FYP period (ICCSD, 2022). If China achieves the goal of carbon neutrality by 2060, it could reduce the release of at least 215 Gt $CO_2$ and reduce global warming by 0.25°C (Pollitt, 2020).

# 4. Near term policy challenges for a long-term target

## 4.1 Emissions peaking: timing and level still subject to debate

China's climate plans are manifested by its 'dual carbon' goals (or 30-60 targets), of peaking $CO_2$ emissions before 2030 and achieving net-zero emissions by 2060 (State Council, 2021a). For the near term, China aims to increase the share of non-fossil energy to approximately 20% of the total energy consumption by 2025 and 25% by 2030, respectively (State Council, 2021a). For its long-term carbon neutrality goal, China sets a target to increase non-fossil energy share to over 80% by 2060 (State Council, 2021a), suggesting a substantial role for negative emissions technologies.

Tsinghua university's Institute of Climate Change and Sustainable Development (ICCSD), one of the key academic partners of the government planning agencies around climate policy, has produced a set of scenarios with differing ambition levels. The development of the composition of China's primary energy consumption, under these different scenarios settings, is shown in Figure 2. Most striking in these scenarios is that both current policies and 'reinforced policies' scenarios are not considered to be in line with the 'well below 2 degree' target of the Paris agreement.

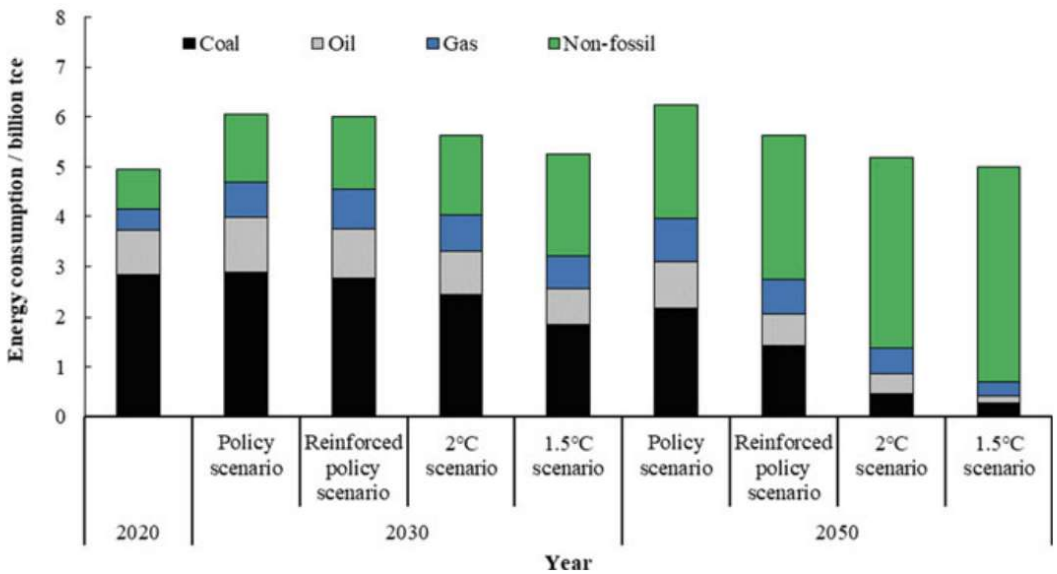


Figure 1. The composition of primary energy consumption in different trajectories towards net-zero emissions in China. Reproduced from (ICCSD, 2022).

China has strong social, economic motivation to decarbonize its development. Socio-economically speaking, the goal of reaching carbon neutrality before 2060 can help China avoid $134 trillion in climate change losses, mostly from heatwaves and floods, by 2100 (Zhao, 2021). It can also bring a range of co-benefits to the societies. For example, climate change mitigation can reduce environmental pollution at local and global levels (West et al., 2013) with concordant positive impacts for health (T. Wang et al., 2020), and spark new opportunities for green investment and economic development (Fabian, 2015). Politically speaking, China's climate leadership is driven by the aspirations of positive international influence as a 'responsible' country. As the world's largest emitter of $CO_2$, aims to project more soft power through its leading commitment to climate change, especially by comparing with some 'slow' Western countries, such as Australia (H. Xu et al., 2021).

Although China has shown its strong 30-60 climate ambitions, it remains unclear when and how exactly China will achieve an emissions peak. Going by results in Figure 2, it is clear that scenarios considered would have trajectories with most of the decarbonization effort post 2030, whilst a fairly wide range of ambition for the period up to 2030 is being considered. Here we uncover China's decarbonisation plan by looking at China's policy plans and emissions projection. China has clear pathways to peak its carbon emissions by 2030 and has initiated four principles to guide its low-carbon transitions (NEA& NDRC, 2022). First, balancing the relations between development and emissions reduction, local and national as well as short-term and long-term development. A combination of coal and other renewables is the core of China's energy transition strategy in the next ten years. Second, safeguarding energy security is the premise for low-carbon and green transitions. Third, providing incentives for saving energy, reducing consumption and emissions and improving efficiency. Fourth, implementing market-based mechanism with the support of governments in planning, support and market monitoring (NEA& NDRC, 2022).

In addition, China has different foci in 14th and 15th five-year plans. From now to the end of 2025, China aims to optimize its industry and energy structure, improve energy use efficacy, restrict the growth of coal consumption and accelerate the reconstruction of non-coal new energy system (State council & Council, 2021). Coal consumption will still be gradually increasing and may peak before 2026 (State council & Council, 2021). From 2026 to end of 2030, China plans to build a clean, low-carbon, secure and high-efficient energy system and achieve low-carbon development paradigms in major industries. Coal consumption will be gradually reduced in this period (State council, 2021a). Coal will still be the dominant fuel through 2030 but the future role of coal in China would be more be on stabilising China's electricity and grid system to better consume electricity produced by decentralized renewables and reduce curtailment (NEA, 2022c; State council & Council, 2021). China restricts any coal-fired plant that only aims to generate electricity from the 14th five-year plan (NEA, 2022c).

Last but not least, we further explore possible more detailed emissions-peaking pathways through looking at China's energy sector. The energy sector is central to achieving China's climate ambition. It contributes >90% of China's greenhouse gas emissions and energy policies are the foci of China's transition to carbon neutrality (International Energy Agency, 2021). With a closer at China's energy sector, we find that China's energy-related $CO_2$ emissions peak is in sight by the end of 2025. First, Dr Fuqang Yang, who participates in the compilation of China's 14th five-year plan on energy development, said that a coal cap will be required in the plan to be reached between 2021-2025 (German Energy Agency & (BMWi), 2021). Second, modelling results estimate that China's carbon peak will be achieved by 2026 with more than 80% probability (S. Zhang & Chen, 2022). Third, at least four of China's s six biggest coal power generators are aiming to peak emissions by 2025 (Downie & Center on Global Energy Policy, 2021). In addition, cement firms have proposed a 2023 peaking target and steel firms target a 2025 peaking date. Fourth, California-China Climate Institutes finds that China's energy-related $CO_2$ emissions are needed to peak by the end of 2025 to achieve the goal of peaking $CO_2$ emissions before 2030 after considering energy intensity reductions, non-fossil fuel energy supply and share, and $CO_2$ intensity reductions for 2025 relative to historical trends and incipient structural changes in China's energy economy (Kahrl et al., 2021).

## 4.2 Carbon neutrality: distributing targets to the subnational level

China has not published clear net-zero pathways in the policy. A general trend will be: After peaking emissions, China will take the shortest time from carbon peak to carbon neutrality in global history (State Council, 2021a) (see also Figure 3). The steepest drop in $CO_2$ emissions will be between 2030 and 2040. The remaining amount of $CO_2$ emissions in 2050 depends, in part, on assumptions about emission targets and the deployment of negative emission technologies (Khanna et al., 2021). The remaining $CO_2$ emissions in 2050 depend heavily on carbon capture and negative emission technologies (Khanna et al., 2021) . Negative emissions are expected to contribute nearly 25% of total emissions reduction from 2020 to 2060 (Z. Liu et al., 2022). Similar to Australia's climate plans, China is also pinning its net-zero emissions hope on the advances in technology such as carbon capture, utilisation and storage (CCUS)(F. Wang et al., 2021; Zeng et al., 2022).

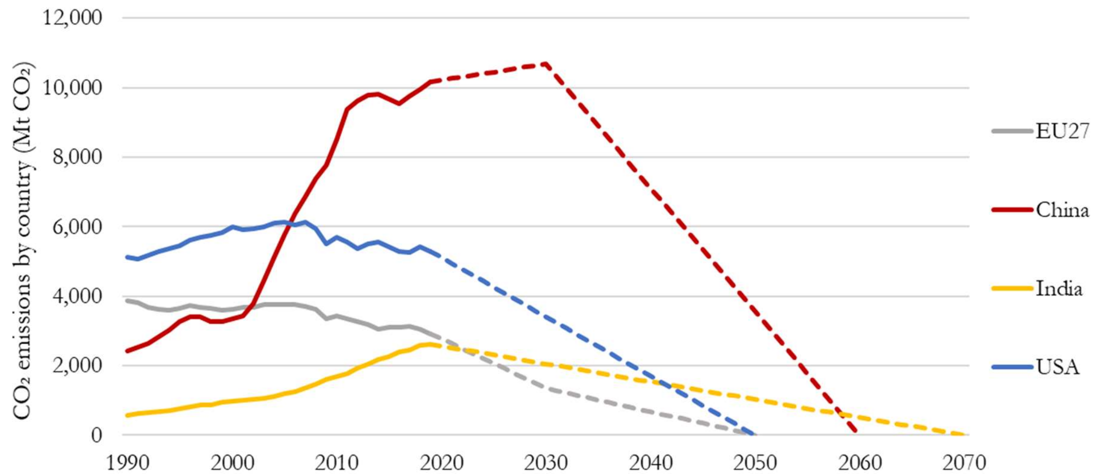


Figure 2. Greenhouse gas emissions as Gt of $CO_2$-eq with climate pledges and implied trajectories to net-zero of the world's major economies. Source: the Global Carbon Project for historical data, projections as linear extrapolations to announced targets. Note that China has a target to peak emissions at an unspecified level before 2030, India's has not announced a date or level when its emissions should peak.

China primarily relies on top-down governance to allocate national emissions goals to provincial governments. For example, the central government categorized the 31 provinces in five groups in the 13th five-year plan period to achieve the target of 18% reduction in carbon intensity, compared to the 2015 level (The People's Republic of China, 2021). Some more developed provinces are allocated with a higher reduction target of 20.5% of carbon intensity, including Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Shandong and Guangdong, while some other less developed provinces are with a lower reduction target of 12% of carbon intensity, including Hainan, Tibet, Qinghai and Xinjiang (The People's Republic of China, 2021). The implementation outcomes of the 13th five-year plan have shown the effectiveness of this design. In 2020, carbon intensity was cut by 18.8% relative to the 2015 level, exceeding the 18% target; the share of non-fossil consumption to the total primary energy. This target was achieved by different efforts from provinces. Jiangsu had reduced its carbon intensity by 24% relative to 2015 levels, carbon intensity in Yunnan fell by 25% by 2020 compared to 2015 level. Inner Mongolia, where carbon intensity decreased by 14% in 2020 compared to 2015 levels, even missing its provincial target of 17% (Z. Liu et al., 2022).

To achieve net-zero emissions, China's instructive policy requires a comprehensive integration of emissions reduction into socio-economic development in a long run and the implementation policies will be greatly relied on the subnational governments with the consideration of local differences (CCCCP & SC, 2021). The primary working principle in the policy requires a command-and-control approach to allocate and ensure each province can achieve the emissions goals allocated (CCCCP & SC, 2021). In addition, it encourages a competition of peaking and reducing emissions among provinces (CCCCP & SC, 2021). The provincial quotas are made between a negotiation between the central government and provincial government. For example, provincial quotas for renewable energy and renewable certificates: After three rounds of proposals, NEA adopted provincial quotas for renewable energy consumption that apply to provincial grid companies and large industrial consumers (which often own their own on-site power generation plants) (German Energy Agency & (BMWi), 2021).

By following the goals being allocated, provincial governments then play a primary role in advancing climate policy design and implementation (Z. Liu et al., 2022). Each province can play their respective strength to initiate locally suitable and adaptive strategies and plans to decarbonise. Accordingly, provinces might formulate specific implementation plans, as well as their targets of reducing energy intensity and increasing the share of non-fossil energy consumption. Furthermore, each province could specifically allocate its reduction targets to each of its cities. Through each city's respective efforts to decarbonize, the carbon intensity reduction target of each province and, by extension, the country's target, can be fully achieved.

Regarding energy transitions, northwest, northeast and inland Chinese provinces will mostly rely on transitions to wind, solar and nuclear energy. Southwest provinces will be based on hydropower, solar and wind. Southeast and coastal provinces will rely on wind (offshore wind) and nuclear energy. To integrate the decentralised energy generation from renewables, from 2022, China aims to enhance cross-provincial energy transport to maximise renewables generation in advantaged provinces and reduce the curtailment of renewable energy (NEA, 2022d).

## 4.3 Coal-fired power: slow phase out

Coal-fired power generation, the focus of the 26th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in November 2021, has ended with 'phased-down' instead of 'phased-out' agreement. China and other emerging economies remain to view coal-fired power favourably due to its flexibility, low-cost, and argue for a role for coal in balancing power generation from renewables (Roy & Schaffartzik, 2021). Coal-fired power has also been explicitly linked to economic development and the provision of employment (Roy & Schaffartzik, 2021).

For China, although coal reduction is the general trend in a long run, the dominance of coal in China's energy supply is expected to remain unchanged for decades to come (NEA, 2022c). This is also apparent in the scenarios developed by Tsinghua's ICCSD (Figure 2), which show the consumption of coal is expected to remain stable through 2030 in the current policy or 'reinforced policy' scenarios. China's installed capacity of coal-fired power generation stood at 1,079 GW by year-end 2021, almost 50% of the global total (China Electricity Council, 2022). Its coal-fired power production was approximately 4,970 TWh over 2021, or roughly 53% of global coal-fired power generation (China Electricity Council, 2022).

For the 13th Five -year plan period, China had adopted a restriction on the installed capacity of coal-fired power plants to a maximum of 1,100 GW, up from 900 GW at the start of the 13th FYP period (NDRC & NEA, 2016b). This target has been achieved, with capacity at 1,041 GW by year end 2020 (China Electricity Council, 2022). In early 2020, when the new Five-Year Plan was being drafted, the China Electricity Council argued for raising this cap to 1,300 GW for the 14th FYP (Myllyvirta et al., 2020). Further, restrictions on provincial-level governments on granting construction permits for coal-fired power plants were greatly relaxed in 2019 and even more in 2020, with investment in the coal-fired power sector further accelerated through post-covid stimulus (Gosens & Jotzo, 2020). Over 2021, 33 GW of coal-fired power plants entered construction, the biggest jump since 2016 (CREA & GEM, 2022).

While the 14th FYP plans for energy are expected in March-June 2022, there is still little clarity on the strategy for coal. After a power crunch in late 2021, caused largely by covid-induced coal supply disruptions and friction between China's liberalized coal market but controlled pricing in coal-fired power (more in section 4.9), support for more robust coal and coal-fired power production capacity grew again. In a recent speech by the premier, Li Keqiang, he stressed the role of coal in a stable energy supply, and encouraged growth of domestic coal mining capacity (People’s Daily, 2022). During the power crunch and turmoil in global coal markets in late 2021, China ordered existing mines in key coal mining regions of Shanxi and Inner Mongolia to immediately raise output by 155 Mt/y (White & Lockett, 2022), and in early 2022 the NDRC approved a further 19 Mt/y in new mine capacity in Inner Mongolia (NDRC, 2022). No total production target for coal mining has been for 2025 or 2030 has been announced yet.

Simultaneously, policy makers had bene indicating that while expansion of coal-fired power production capacity may be required to some extent, restrictions would instead focus on the total production of coal-fired power. This phase-out strategy has been dubbed 'stand first, break later (先立后破)'. In short, coal-fired power would help China with security of power supply and grid stabilization, while quickly expanding solar and wind power, and will be gradually phased out and replaced by these additions of renewables (See also section 4.12). The strategy emphasises that coal power generation will not increase despite coal-fired power plant capacity increases (NEA, 2022c). In March 2022, the NEA stated that "in principle" no new coal-fired power would be permitted, albeit with two important caveats. First, plants for co-generation of power and heat, which is a much more efficient utilization of the primary energy in coal, would still be allowed. Secondly, the notice indicates allowing "to a certain extent" new power plants that are needed to ensure security of supply or grid stabilization (NEA, 2022e).

Reducing average energy intensity is another key policy principle for managing coal-fired power. China aims to reduce the average energy intensity of thermal power from 305.5 grammes of standard coal equivalent per kilowatt-hour (gce/kWh) in 2020 to 300 gce/kWh by 2025, and targets flexibility retrofits for 200 GW of coal-fired capacity(NDRC & NEA, 2021). Any new coal-fired units can in principle only be ultra-supercritical units with energy intensity below 270 gce/kWh (NDRC & NEA & Agency, 2021). Based on this it could gradually phasing out higher energy consumption and backward coal-fired power plants, especially small plants with capacity lower than 300 MW (NEA, 2022c). Some provinces, such as Sichuan Province, have stopped the approval of new coal-fired plants from 14$^{th}$ FYP period (The People's Government of Sichuan Province, 2022).

To ensure the solvency of state-owned power companies and maximize provincial tax revenue, provincial governments had also favoured dispatch of within-province coal plants over trading power between provinces—creating a system known as 'provincial fortresses'(German Energy Agency & (BMWi), 2021). Power market reforms that were restarted in 2015 have been aimed at gradually resolving these issues through a combination of market and administrative measures, including phasing out planned to operate hours and encouraging power trading among provinces (MoF, NDRC & NEA, 2020).

Moreover, China's 5.2 million coal miners, representing 0.6% of its workforce in 2017, has dropped to 2.6 million in 2020, and a broad employment base is needed to provide for intersectoral labour transfer that will result from the changing energy mix to ensure a fair transition in the energy transition (Eaton, 2021).

## 4.4 Natural gas: considered as transition fuel

With emerging air pollution issues such as $SO_2$, $NO_X$ and $PM_{2.5}$ especially in North and Northeast China, coal has been increasingly replaced in heavily polluted areas by natural gas to tackle air pollution and mitigate climate change (C. Liu et al., 2021). After launching the Air Pollution Prevention and Control Action Plan, which aims to reduce coal consumption in electricity generation and heat supply to improve air quality (C. Liu et al., 2021), coal-to-gas switching is a milestone showing China's effort in optimizing its energy structure to improve air quality and reduce $CO_2$ emissions, which was one of important strategic plans from 2014 to 2020 (H. Chen et al., 2020). The plan has been applied to electricity generation, collective heat supply and home heaters. For example, the Work plan for Air Pollution Prevention and Control in Beijing-Tianjin-Hebei and Surrounding Areas in 2017required 28 cities to complete the replacement of 50, 000-100,000 coal-fired home heaters by gas or electricity(H. Chen et al., 2020).

Around 70% of carbon dioxide emissions from energy consumption comes from coal consumption, coal-to-gas switching has helped China limit the coal consumption and lead to a reduction in Chinese $CO_2$ emissions (Jia & Lin, 2021). Gas-fired electricity emits much less $CO_2$ (around 50% less) than coal (Morton, 2018). As a transition fuel, from 2005 to 2019, almost 532 million metric tons, equivalent to 65%, of decline in $CO_2$ emissions in US is attributed by the shift from coal-fired to natural gas-fired electricity generation (McGrath, 2021). From 2020, we witness increasing demand of natural gas from Asia and increasing production from US, Russia, Australia and Qatar (NEA, 2021a). In China, the carbon emission reduction amount is estimated to reach 126.67-299.50 million tons under different substitution scenarios of coal by 2030 (Z. Chen et al., 2022).

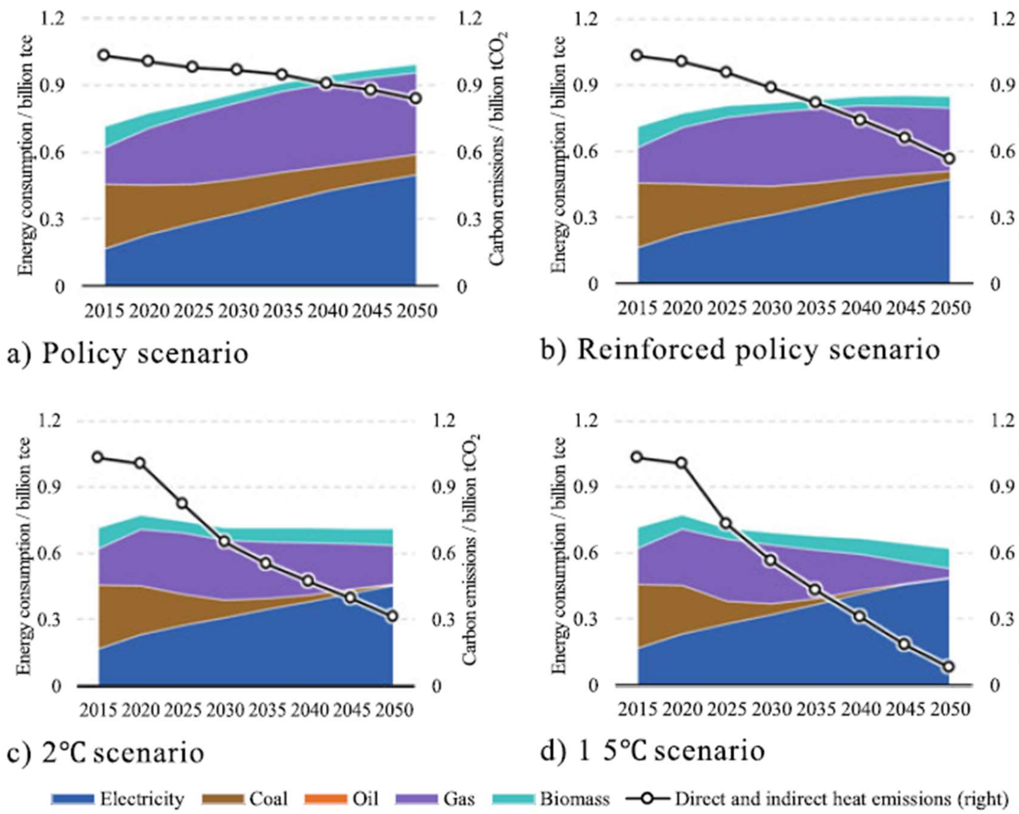


Figure 3. Energy use (by fuel type) and carbon emissions under different scenarios under the 'policy' scenario (top left), 'reinforced policy' scenario (top right), '2 degree' scenario (bottom left) and '1.5 degree' scenario (bottom right) of Tsinghua's ICCSD (ICCSD, 2022).

Natural gas will become China's transitional fuel as the most realistic solution to renewables intermittency (Safari et al., 2019). China has shown strong demands on natural gas from now to 2040 at least (Figure 3) and considered it as a transition fuel for replacing coal in electricity generation (NEA, 2021a). It has surpassed Japan to become the largest importer of oil natural gas in 2018. China will also host the global natural gas conference in 2025 and promote the role of natural gas in reducing carbon emissions (NEA, 2021a). China is estimated to consume around 450,000 million cubic meter natural gas per year by 2025 and 600,000 million cubic meter natural gas per year by 2030, and it will keep going till at least 2040 (NEA, 2021a). Natural gas has also been proposed as both low-carbon lase load power and a grid-stabilization power to facilitate China's green and low-carbon transitions (NDRC & NEA, 2022b)

China will remain a large importer in global market for gas. Just recently, China agreed a 30-year contract to buy gas from Russia (A. Chen, 2022). However, the annual 50 billion cubic meter natural gas will not meet China's projected need to import around 220 billion cubic meter natural gas per year from 2025. Australia will therefore still have opportunities to supply natural gas to China.

## 4.5 Renewable electricity: fast growth, but not accelerating

Driven by climate ambitions and corresponding stronger policy support, China has been the global engine of renewable capacity growth, responsible for over 40% of the world's new installations during 2011-2020 (IEA, 2021). China's installed renewables capacity reached 1,054 GW by year end 2021, or about 45% of global capacity (China Electricity Council, 2022).

Hydropower has a long history in China and remains the largest source of renewable electricity in China. Installed hydropower capacity and output continue to grow, accounting for 35% of total renewable capacity additions since 2000. China leads the world in hydro capacity, at 390 GW, of which 31.5 GW is pumped storage (China Electricity Council, 2022). . In 2021, hydroelectricity output stood at 1,340 TWh, or about 16% of total output.

In recent years, the bulk of the growth in renewable power output has come from solar PV and wind. Around 60% of renewable capacity additions since 2000 has come from solar PV and wind power, with record installation of 127 GW in 2020, and 92 GW in 2021 (China Electricity Council, 2022). Offshore wind capacity has recently also started to grow rapidly in China, with 17 GW installed in 2021, to a total of 26 GW, or almost half of the world's off-shore wind capacity (NEA, 2022b). In addition, China has 54 operational nuclear reactors, totalling about 54 GW, with a further 30 GW under construction (WNA, 2022).

Wind and solar provided a combined 11.7% of power production in 2021 (China Electricity Council, 2022). These technologies are considered by most analysts to play the most important role in decarbonizing the power sector. A review of different studies suggests a range of this share in power output of about 34-73% by 2050 (Khanna et al., 2021). Tsinghua's ICCSD sees about 42% non-hydro power, 12.5% hydropower, and 20% nuclear power by 2050, under its 'reinforced policies' scenario. The big difference with its 2 degree compatible scenario is that this scenario has about 60% more wind and PV (Figure 2).

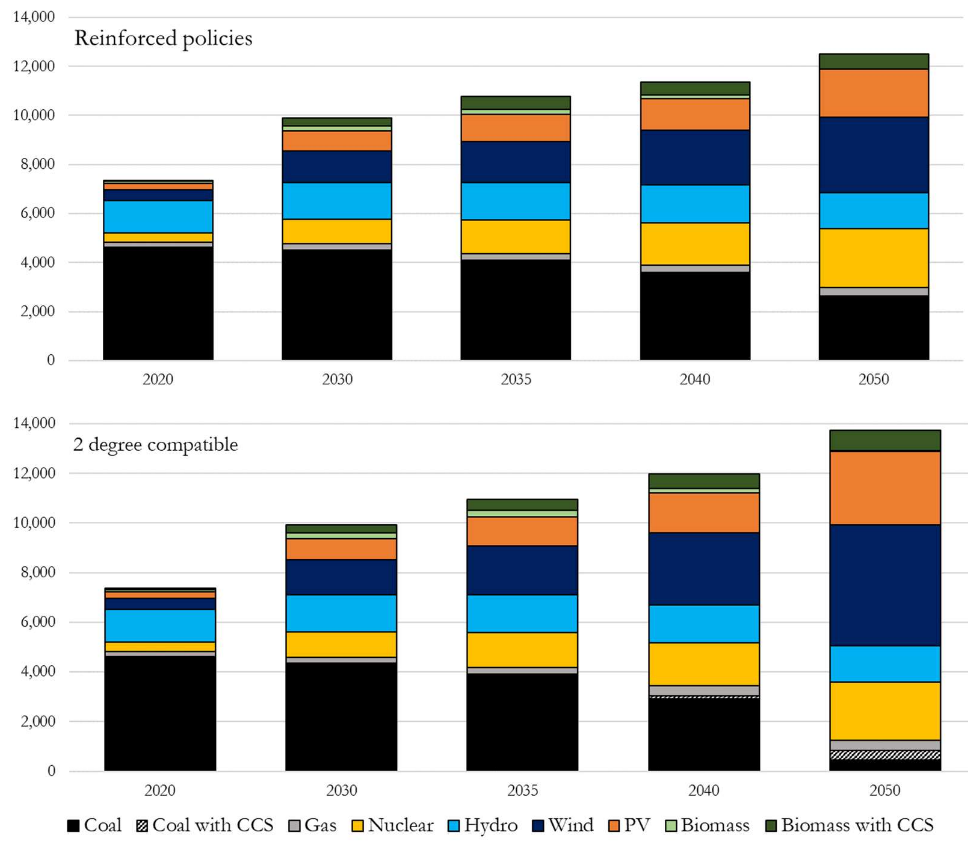


Figure 4. Projected power generation by source (TWh) under the 'reinforced policies' scenario (top) and 2 degree compatible scenario (bottom) of Tsinghua's ICCSD (ICCSD, 2022).

For the nearer term, a draft plan released in early 2021 suggested a target of 18.6% of electricity generation from non-hydro renewables by 2025, and 26% by 2030 (Energy Iceberg, 2021; NEA, 2021b). The only official target set so far is to get to 1,200 GW of wind and solar by 2030. This is not an incredibly ambitious growth target. It suggests an annual addition of 66.5 GW of wind + solar through to 2030, roughly similar to the growth over 2015-2020 (Figure 3), but well short of the 127 GW installed in in

2020, and 92 GW installed in 2021 (China Electricity Council, 2022). This 1,200 GW target is therefore likely one on which China under promises but will over-deliver, as it has regularly done with renewables targets in the past.

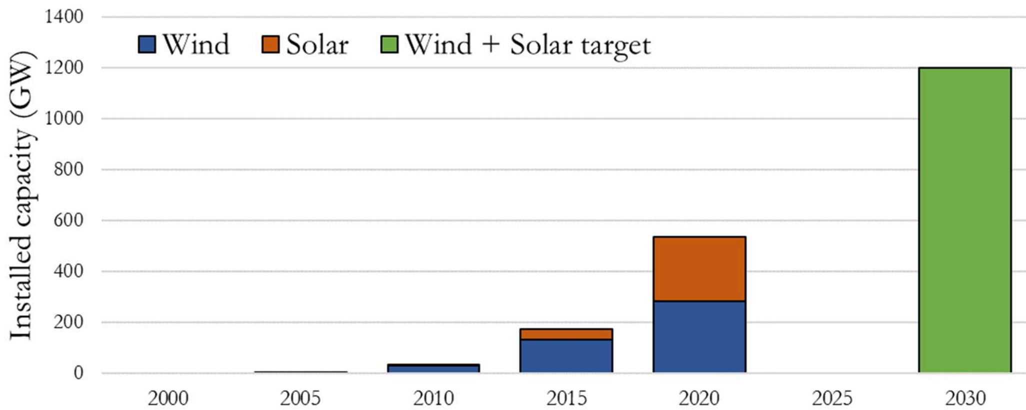


Figure 5. Installed capacity of wind and solar, compared to China's 2030 target of 1,200 GW.

China renewables investments reached USD 83.6 billion in 2020, including 66% in wind energy (both onshore and offshore), 30% in solar PV, 4% in biomass and waste and 0.5% in small hydropower (Gallagher & Qi, 2021a). China is also the world's dominant supplier of renewables and battery manufacturing. It manufactures around 70% of global solar modules, 50% of wind turbines and 90% of lithium-ion batteries (REN21, 2021).

Xi Jinping emphasizes on the 36th Central Committee of Chinese Communist Party Collective Study in 2022 that the additions of solar and wind generation capacity fuel China's energy revolution and decarbonisation plans (Xinhua News Agency, 2022). Solar and wind energy are increasingly competitive in the power market and could be even cheaper than gas and coal in some countries, such as Australia (Graham et al., 2020). The costs for solar photovoltaics, wind, and battery storage have dropped markedly since 2010. If cost trends for renewables continued, studies find that approximately 62% of China's electricity could come from hydropower, solar, wind and nuclear by 2030, and with a cost that is 11% lower than a business-as-usual approach (He et al., 2020). If China plans to peak its $CO_2$ emissions by 2030, the addition of 76 GW total solar and wind capacity per year is needed (Kahrl et al., 2021).

The scalability of nuclear is another pillar supporting China's energy transitions. 14th Five-Year Plan (2021-2025) shows China plans to reach 70 GWe gross of nuclear capacity by the end of 2025 (NDRC, 2021a). Nuclear is the second most cheap renewable energy in China. In 2017, the wholesale price of nuclear electricity was 0.403 RMB/kWh, slightly higher than hydro (0.259 RMB/kWh) and coal (0.372 RMB/kWh) but lower than wind, solar, and biomass. China's nuclear technology has been drawn from France, Canada and Russia, with local development based largely on the French element (H. Xu et al., 2021). However, there is less consensus in the reviewed studies on nuclear power's future role, with its projected generation share ranging from today's 5% share to increase significantly to 28% of generation by 2050 (Khanna et al., 2021). Estimates of China's nuclear capacity by 2050 range from 150 GW to 500GW (Yu et al., 2020). More recently, China aims to actively promote and expand nuclear energy to grid balancing (The People's Government of Haiyang, 2022), supply heat, steam and electricity (NEA, 2022a), and also produce hydrogen more recently .

However, challenges after removing subsidies for renewables are emerging. During the 13th FYP period (2016-2020), China revised down feed-in tariff (FiT) rates and phased out FiT subsidies from the central government for new wind and solar projects by the end of 2020 (NDRC, 2016b). It completely ended public funding for new offshore wind farms and halved its budget for subsidising new solar power from CNY 3 billion (USD 460 million) to CNY 1.5 billion (USD 230 million) (REN21, 2021). China announced plans to phase out feed-in tariffs for solar PV starting in 2021(REN21, 2021). Thus, we witnessed that China's share of global renewables growth jumped 50 per cent for the first time in 2020 amid a rush to finish projects before government subsidies were phased out (REN21, 2021). We also saw the annual solar PV capacity additions rise from 29 GW in 2019 to 49 GW in 2020, and installations in 2020 concentrated in the fourth quarter (German Energy Agency & (BMWi), 2021). After exceptional expansion over the past two years, this rapid growth in China is expected to decelerate in 2022, accounting for 43% of global renewable capacity growth (Xue, 2022).

China has now gradually transitioned away from the scheme to other support instruments, including competitive auctioning, voluntary green certificate trading and renewable portfolio standards (RPS), which is a command-and-control instrument that sets annual targets on shares of renewables and non-hydro renewables in electricity consumption by province (NEA, 2020). China has reformed the green certificate scheme as a complementary policy to the mandatory RPS scheme since 2021. Tradable green certificates[1] or tradable renewable energy certificates systems are schemes that establish a market for the "greenness", i.e., the non-energy environmental attributes of renewable energy, to support the eligible technologies (MoF, NDRC & NEA, 2020). Although voluntary green credits or certificates are still available for purchase, the market for these certificates have been thin, because the credits represent a transfer of subsidy payment obligation from the government to the purchaser, and therefore lack additionality (German Energy Agency & (BMWi), 2021). In addition, although generation costs from new solar and wind plants in China dropped 82 percent and 33 percent over the past decade, further cost reductions will be more limited (Figure 4).

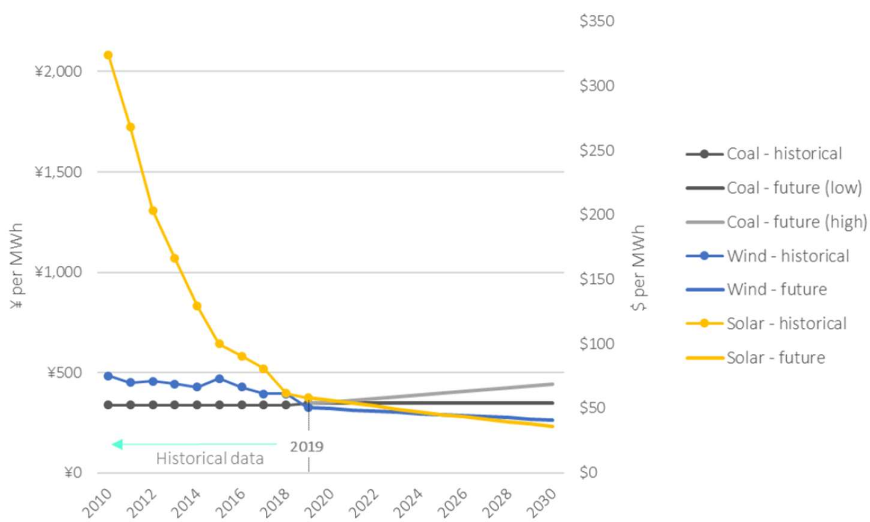


Figure 6. Generation costs of solar, wind and coal-fired power in China between 2010 and 2020, with projections through to 2030. Source: (Busch et al., 2021).

## 4.6 Hydrogen: focus on use as a transport fuel, domestic production

Hydrogen has a special role than other renewables that most are used for direct electrification because it can meet high-temperature requirements and can be used in the building, transport, and industry sectors (J. Chen, Li, Li, et al., 2021). Among industrial sectors, the steel industry will see the biggest increase in hydrogen consumption, followed by the chemical industry which will see an increase of hydrogen consumption until 2030 and a decline after 2030 (German Energy Agency & (BMWi), 2021). With the

[1] In China's green certificate scheme, one green certificate accredits 1 MWh of non-hydro renewable electricity and can be traded to provide renewable generators an additional revenue to electricity sales, with large-scale onshore wind and solar PV projects currently being eligible.

significant decrease in future costs, hydrogen production from water electrolysis will be the main supply source of zero-carbon hydrogen (70%) (J. Chen, Li, Li, et al., 2021).

Rather than like Japan (Kurmelovs, 2022) and South Korea (Australia-Korea Business Council, 2021), who is importing or planning to import hydrogen from Australia, China is mainly target at produce hydrogen domestically. More than 40 Chinese cities have Issues hydrogen energy development plans and guidance and hydrogen generation (X. Zhang, 2021). China is the world's largest producer and consumer of hydrogen (IEA, 2021). In 2018, China accounted for about 21 million tons of hydrogen production, and China consumed 22 million tons. Energy Iceberg forecasts these figures to rise to 35 million tons in 2030 and 60 million in 2050 (German Energy Agency & (BMWi), 2021).

However, the transition towards low-carbon production of hydrogen in China is still at an early stage of development, and fossil fuels account for 99% of China's hydrogen production, including 62% from coal, 19% from natural gas, as well as 18% from petroleum, coke oven gas and chloralkali tail gas (X. Zhang, 2021). The high share of coal-based hydrogen in total production relates to the low cost of coal: China has an established coal infrastructure and lacks domestic gas supplies as an alternative for hydrogen production. According to the IEA, coal-based hydrogen combined with CCUS (Carbon capture, utilisation and storage) which has a $CO_2$ intensity of 2 kg $CO_2$/kg $H_2$ would represent the lowest-cost and cleanest potential hydrogen production route in China with about US$ 1.48/kg H2 (IEA, 2021).

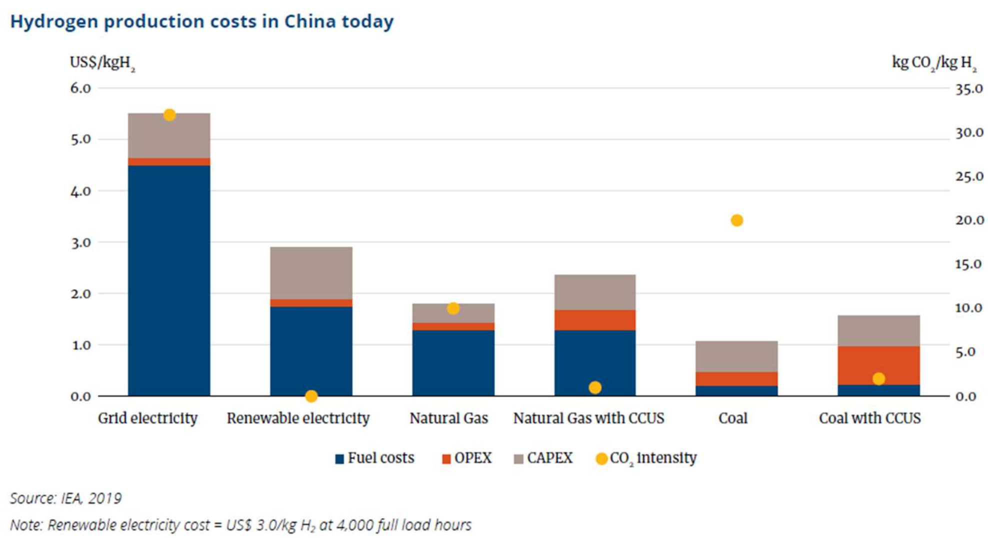


Figure 7. Production costs of hydrogen via different technological routes. Source: (German Energy Agency, 2021).

The 14th five-year plan aims to accelerate hydrogen development (State Council, 2021b). Transport sector in China has viewed hydrogen as a replacement of petrol in future. The number of hydrogen refueling stations reached 128 in 2020, and it is planned to be 200 in 2025, 1500 in 2035 and 10,000 in 2050 (G. Chen, 2021). In addition, 28 provinces have initiated relevant policies to encourage hydrogen development (China Business Research Institute, 2022). Advancing provinces, such as Beijing and Shandong, have initiated five-year or ten-year plans for hydrogen industry development (Beijing Municipal Bureau of Economy and Information Technology, 2021; People's Government of Shandong, 2020). Being plans to add 37 more hydrogen refueling stations, and construct a hydrogen industry valuing >100 billion yuan by 2025 and helping reduce 2 million tons of $CO_2$ emissions (Beijing Municipal Bureau of Economy and Information Technology, 2021). Shandong aims to construct 100 hydrogen refueling stations, produce >50,000 hydrogen fuel cells, stabilize electricity system and construct a hydrogen industry valuing >100 billion yuan by 2025 (People's Government of Shandong, 2020). By 2030, Shandong will have >200 hydrogen refueling stations and construct an international hydrogen base connecting big data, artificial intelligence and wise transport (People's Government of Shandong, 2020). By 2060, almost one-fifth of electricity is used to generate hydrogen (IEA, 2021)

In March of 2022, Inner Mongolia proposed a more comprehensive hydrogen development plan and aims to expand hydrogen's usage in chemical and steel industry and have the capacity of produce 0.5 Mt of green hydrogen per year by 2025 (People's Government of Inner Mongolia Autonomous Region, 2022). However, there is still a large gap between China and the advanced international hydrogen producers on key core technologies, including hydrogen production by the electrolysis of water, storage/transportation and fuel cell manufacturing (X. Zhang, 2021). Although China's largest steel producer, Baowu Group, has piloted hydrogen-rich carbon circulation in blast furnaces in 2021, China still faces great challenges and uncertainties in developing chemical, and iron and steel production based on green hydrogen (Y. Lin et al., 2021). Only 1% of hydrogen produced in China is from electrolysis of water and the cost to produce electric hydrogen (>20 CNY/kg) is at least double that from coal in China (X. Zhang, 2021). China needs to learn and collaborate with countries with more advanced technology in green steel making, such as Japan, US, South Korea and Germany (Y. Lin et al., 2021).

## 4.7 Zero-carbon mobility: EVs reign but strong support for fuel cell vehicles

Electric vehicles are a large and rapidly growing market segment in China. Over all of 2021, EV sales totalled 2.9 million units, or 11.2% of total sales; in the last quarter of the year EV sales even made up as much as 18% of total sales (NBS, n.d.). The latest strategic plan on new energy vehicle development published in October 2020, and it aims to accelerate China's transition to hydrogen and fuel cell electric vehicles as a catalyst to stimulate the integration of energy, transport and telecommunication (State Council, 2020). A few ambitious targets were set in the plan. By 2025, the average power consumption of new pure electric passenger vehicles will be reduced to 12.0 kWh/100 kilometres, the sales of new energy vehicles will reach about 20% of the total sales of new vehicles, and highly autonomous vehicles will be commercialized in limited areas and specific scenarios (State Council, 2020). By 2035, China will become a a global leader in new energy vehicles. Pure electric vehicles have become the mainstream of new sales vehicles, vehicles in the public sector will be fully electrified, fuel cell vehicles will achieve commercial application, highly autonomous vehicles will achieve large-scale applications, the charging and swapping service network will be convenient and efficient, and the construction of a hydrogen fuel supply system will be steadily advanced (State Council, 2020). In addition, the latest 14$^{th}$ FYP of green transport development sets more specific targets for the share of new energy vehicles (Ministry of Transport, 2021). By 2025, new energy vehicles should constitute 72%, 35% and 20% of national urban buses, taxis (including e-taxis) and good delivery, respectively (Ministry of Transport, 2021).

In September 2020, China announced a new policy to develop hydrogen and fuel cell applications, subsidies were waived for hydrogen and fuel cell electric vehicles purchasers but was transferred as awards that are available for producers who have significant progress in innovation and application (MoF et al, 2020). . This emphasis differs significantly from the hydrogen and fuel cell strategies of other leading economies (Y. Li & Taghizadeh-Hesary, 2022b). China aims to develop an whole chain of hydrogen and fuel cell electric vehicles from raw material to products, from fuel generation to consumption and from technology to policy (MoF et al, 2020). It is a milestone shows that China has transferred from a market-based mechanism to a more command-and-control approach to promote the integration of new energy vehicles and transportation (State Council, 2020). The main driver is that hydrogen and fuel cell electric vehicles are only economically competitive compared to vehicles with other powertrains as passenger cars. But hydrogen and fuel cell electric vehicles remain uncompetitive in the bus and truck fleet and the total cost of new energy buses and trucks is about twice as high as the ones running on fossil fuels (Y. Li & Taghizadeh-Hesary, 2022b).

Hydrogen refuelling stations currently operating in China at about $12.2/kg (not considering government subsidies) are more competitive than regular hydrogen purified from industrial by product hydrogen, produced from renewable energy sources delivered via pipelines, compressed hydrogen trucks, and liquid organic hydrogen transporters (Y. Li & Taghizadeh-Hesary, 2022b). However, the cost of hydrogen makes fuel cell electric vehicles economically uncompetitive as passenger vehicles due to the large subsidies provided by the Chinese central and local governments for the capital cost of fuel cell electric vehicles. Clearly, passenger fuel cell electric vehicles are already competing with other alternative power systems in China. In order to balance the development of hydrogen and fuel cell vehicles, China also needs to accelerate the development of the fuel cell electric vehicle supply chain.

## 4.8 Carbon market: sectoral coverage and prices expected to grow

From 2013, China has established eight regional Emission Trading Systems (ETSs) to pilot emission trading. The Chinese national carbon market was announced in 2011, launched in late 2017 and started operation on 16 July 2021. As of December 31, 2021, 178.8 million tons of allowances had been traded in the national carbon market, with a value of CNY 7.7 billion. The national carbon emissions trading market had been in operation for 114 trading days (Slater et al., 2022). The cumulative trading volume of listed trading was 30.8 million tons, with a total value of CNY 1.5 billion; the cumulative trading volume of bulk trading was 148 million tons, with a total value of CNY 6.2 billion. The closing price on December 31 was CNY 54.22/tonne, up by 13% from the opening price on the first day (Slater et al., 2022).

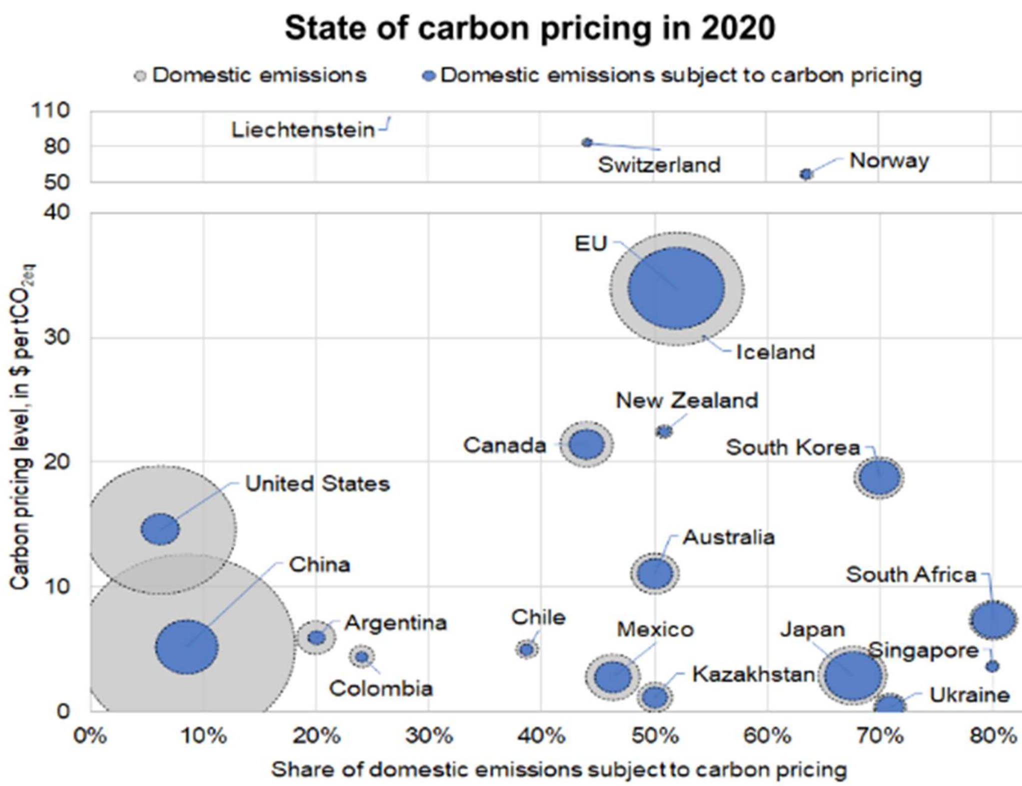


Figure 8. Carbon price levels and domestic emissions coverage of global major economies and large emitters. Source: (Heudé et al., 2021). Note that emissions covered by China's ETS are currently more than 40% of total emission, since the entire national power sector was included in 2021.

However, China's current emissions trading system (ETS) is restricted to power sector and covers only coal- and gas-fired power plants. Compared with other major economies, the share of emissions subject to the ETS is still limited in China (Figure 8).

Most carbon markets elsewhere in the world, implement a system of 'cap and trade', meaning a quantitative ceiling of carbon emissions allowances is set for all potential emitters, which receive their allocated emissions quota either by auction or through free allocation. Emitters may reduce emissions so as to free up allowances to sell, or to reduce the need to purchase these (Goulder & Schein, 2013).

In China, the ETS does not have an absolute cap, and rather works with a benchmark emission intensity system for different types of power plants. Power plant operators receive emission allowances for every MWh of electricity generated, which means more allowances are present in the market when more electricity is generated from coal or gas. These allowances are currently all allocated freely. If a plant's emissions intensity is higher than its applicable benchmark (typically when the plant is less efficient than the benchmark implies), it will face an allowance deficit and will have to buy allowances to be compliant. Conversely, if its emissions intensity falls below (i.e., performs better than) the benchmark, the plant will have received more allowances than it would need to surrender for its verified emissions, and can sell or potentially bank the surplus, which provides a financial incentive for reducing emissions intensity. The Chinese government thus considers the carbon market mainly to reduce the emissions intensity of power plants using fossil fuels (Cao et al., 2021).

This mechanism means that, in China's current carbon market, renewables generation misses out on the price uplift in markets and the development of renewable energy is therefore not incentivized (Liao & Yao, 2022). The dilemma obviously exists with a close look at China's electricity market. ETS aims to reduce power-related emissions, but it will add to electricity costs, whilst the government considers affordable electricity an important necessity (Cao et al., 2021). In addition, the current design of China's national carbon market neglect regional disparities in the allocation of carbon emission allowances, which is based on production, and western China, such as Shaanxi, Xinjiang and Inner Mongolia, bears most of the cost of mitigation (Liao & Yao, 2022).

In addition, although reduction of coal consumption was found in participating coal-fired power plants, China's carbon emission trading system was found to have no effect on changing coal efficiency of the power plants (Cao et al., 2021). The reduction was achieved by decreasing electricity production because of increasing price of coal and controlled electricity prices (Cao et al., 2021). The Chinese government allows electricity prices to increase up to 20% versus a fixed benchmark, which creates difficulties generating a profit for these power plants In times of high coal prices, or other operating costs (M. Xu & Singh, 2021).

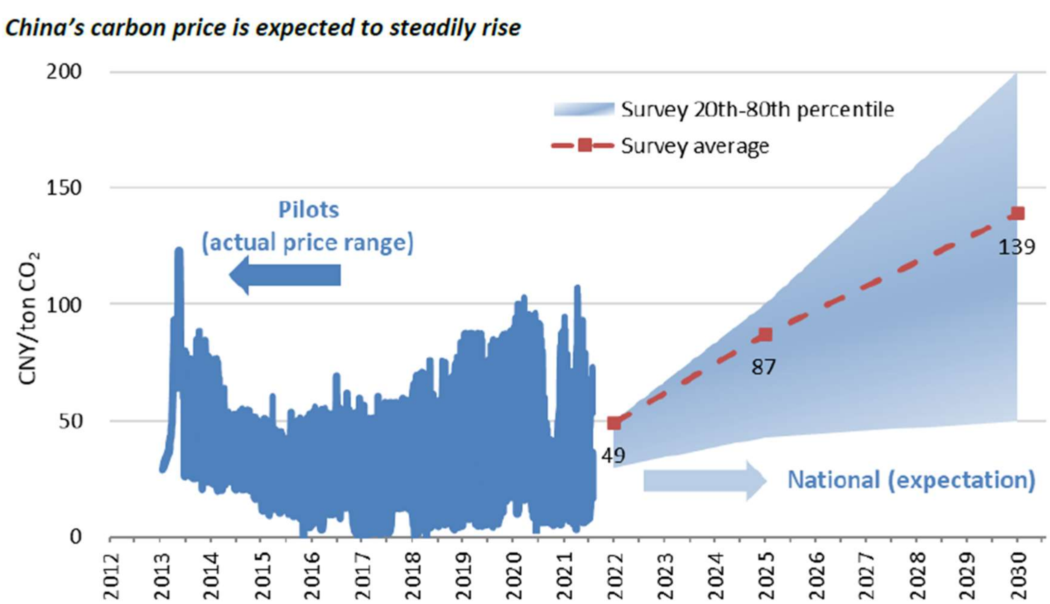


Figure 9. Range of carbon prices in pilots and estimated prices for the national system by 2030. Source: (Slater et al., 2022)

Although there are challenges and restriction in China's existing ETS, it also shows success potentials on decarbonisation by putting a price on $CO_2$ emissions if three obstacles could be addressed. First, the challenge of effective monitoring, reporting and verification of carbon emissions of participators (Mathieu et al., 2021). Second, as shown in the Figure 9, the price of trading in the Chinese national carbon market and pilot have fluctuated between near zero and CNY100/tonne, exceeding the range of ETS fluctuations in most parts of the world (Heudé et al., 2021). Some studies have concluded that there is a price bubble in China's carbon market, which is closely related to the imperfect market mechanism including quota allocation mechanism, legislation and market entry mechanism (Y. Xu & Salem, 2021b). To avoid speculative trading and provide a better investment environment in the carbon market, China's carbon market needs to assess the carbon market bubble and improve the mechanism construction. Last but not least, the time and extent to integrate renewables into the existing carbon market are unsure and how to control its cumulative impacts should be anticipated.

In summary, nowadays ETS in China is more like a political task and is expected to play a modest role in decarbonizing the power sector between 2020 and 2030 (Mathieu et al., 2021). The allowance allocation is output-based and thus designed not to result in major electricity price increases. It is also the reason that the vast majority traded only in the month of December before the compliance deadline. In the longer term, China's carbon market is expected to grow into a large market, with expanded sectoral coverage, and trading value of CNY 100 billion, which will provide a price signal and even financial support for carbon emission reduction across the economy (Slater et al., 2022).

## 4.9 Power market reform: slow progress in crucial reform for renewables

The Chinese electricity market remains strongly guided by pricing policies. In most cases, tariffs charged to household and different types of industry consumers, feed-in tariffs paid to power generators, and transmission and distribution charges, are set by the pricing department of the NDRC (IEA, 2018). Feed-in tariffs paid for power generation are differentiated by technology and by province; those for coal-fired power generation range between 250 CNY/MWh (US$40) in poorer inland regions, to 450 CNY/MWh (US$70) in richer coastal provinces (IEA, 2018). Feed-in tariffs for wind, solar, and biomass power generation were originally set at much more generous levels, but these have been adjusted downwards at regular intervals, and have recently been discontinued entirely (see section 4.4).

The market for thermal coal has officially been fully liberalized, but the NDRC has kept a close eye on coal prices, using a 'green zone' of between 500 to 570 CNY/t for 5,500 kcal coal in recent years; apparently the right balance between the financial interest of coal miners and power plant owners (S&P Global, 2020). Following dramatic price increases in global coal markets, the NDRC raised this green zone to between 570 and 770 CNY/t in February of 2022. A spokesperson for the department commented this did not mean a return to pricing policy for coal, but analysts generally expect the NDRC to step in when prices drift outside of this range (Lee, 2022; S&P Global, 2020).

A new round of power market reforms was kicked off in 2015, when the central leadership published its "Opinions on further deepening the reform of the electric power system" (also known as Document No. 9) (CPC Central Committee and the State Council, 2015). The objectives of this round reform were to let market-based mechanism play a much greater role in wholesale and retail pricing, and to establish transparent transmission and distribution tariffs, separated in retail prices. Reforms also aimed to increase electricity transmission between relatively independently operating provinces and regions, something considered to improve both economic efficiency, by interprovincial balancing, as well as improve the consumption of renewable electricity, by allowing exports in case of local grid congestion (IEA, 2018).

This headline document was followed by a series of trial and implementation plans (overview from H. Guo et al., 2020), including on direct power purchasing (with time scales in weeks, months or years) (NDRC & NEA, 2016c), on reducing the allocation of guaranteed power offtake from coal-fired power plants (NDRC & NEA, 2017b), spot power market regulations (NDRC & NEA, 2017a), on regulating inter-provincial and inter-regional power transactions in the forward (bilateral) market and on prioritizing the transmission of renewable electricity over inter-provincial and inter-regional transmission lines (NDRC, 2018). This was followed up with a series of supply-side reform pilots, and a number of spot market pilots (IEA, 2018).

In October of 2019, the NDRC announced one fundamental change to power pricing, with a floating tariff for coal-fired power (Energy Iceberg, 2019). Prices were allowed to fall 15% below, or rise 10% above, the previously fixed feed-in tariff. In October 2021, this float mechanism was adjusted to allow prices to rise or fall by 20% versus this benchmark, largely in response to a power crunch caused by power plant operators unwilling to generate electricity, as prices in the liberalized coal market had risen to levels well exceeding the revenue from electricity sales in the more controlled power market (Reuters, 2021). Simultaneously, all government set tariffs for consumers with 10 kV+ connections were cancelled, and these were ordered to acquire electricity through market transaction instead (NDRC, 2021b).

These measures have already had some success in supporting the consumption of renewable electricity, as visible in falling curtailment rates. In 2020, wind curtailment declined to 3%, down from 7% in 2018 and a peak of 17% in 2016. Solar curtailment in 2020 fell to 2%, down from the peak 11% in 2015 (German Energy Agency, 2021). This was also spurred by rules stating grid companies were obligated to compensate renewable electricity generators for a minimum number of full-load hours every year, guaranteed in take-or-pay provisions in power purchase agreements.

Beyond these measures, China has introduced Green energy certificates, and although the lack of green electricity purchase obligations makes this an entirely voluntary scheme, renewable electricity appears to garner a price premium in direct power purchasing markets (Zhu & Jiayin, 2020). The current design of the carbon market (section 4.8) does not create additional competitiveness of renewable versus coal-fired power generation.

In summary, as of early 2022, much of the ambitious reform of the power market is still in the planning or piloting phase. In January of 2022, however, the NDRC and NEA published "Guiding opinions on accelerating the construction of a national unified electricity market" (NDRC & NEA, 2022a). The new impetus for power market reform is likely largely due to a combination of the recent power crunch and the new ambition for carbon peaking before 2030. The high-level plan aims to fast-track reform, with unified national power market system "initially established by 2025" and "basically completed by 2030". Key design feature of this unified market would be market-driven inter-provincial and inter-regional electricity trading, and full participation of both fossil and renewable generators in the market (Carbon Brief, 2022; NDRC & NEA, 2022a).

While power market reform therefore remains a fairly long-term policy agenda, any progress may be expected to benefit the consumption of renewables. The weaknesses in the current system to deal with price spikes as revealed over 2021, can be expected to give additional impetus to the pace of reform.

## 4.10 Steel making: focus on scrap recycling more than hydrogen

China is both the largest producer and consumer of steel in the world, by some margin. In 2020, the country produced a 1,064 Mt of crude steel, justify of 60% of global production, almost all of it for domestic consumption (Figure 3). China's consumption of coking coal similarly makes up about 60% of total global consumption. The steep growth in steel production and consumption over a relatively short time period also means that most of this steel in still in the stock in-use, and that volumes of steel that becomes available as scrap are still relatively limited. This is turn pushes up demand for primary steel, made with iron ore and coking coal.

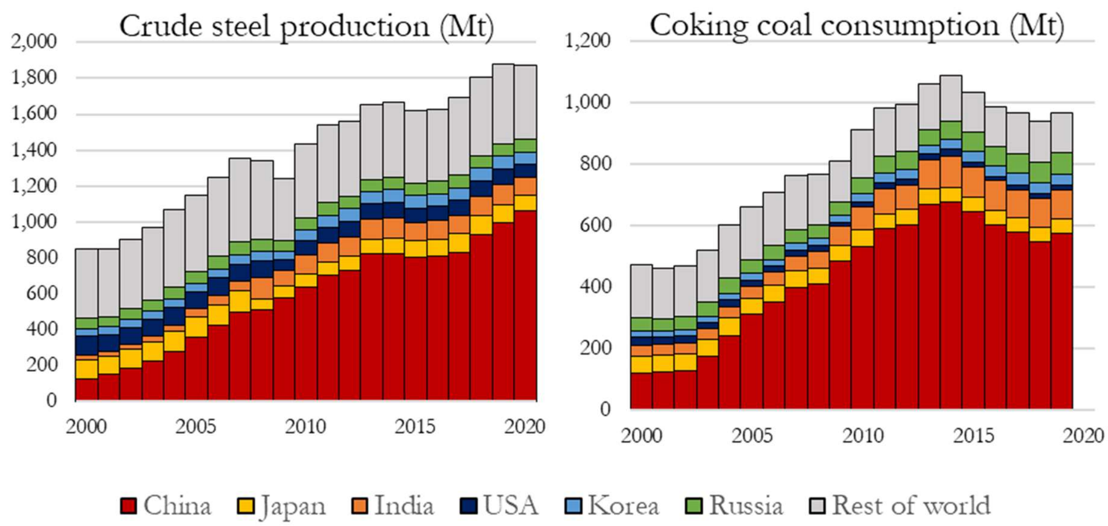


Figure 10. Global steel production and coking coal consumption. Sources: (IEA/OECD, 2019; World Steel Association, 2020).

Globally, the steel sector is responsible for about 7 to 8 percent of carbon emissions. The heavy use of steel in China, driven largely by construction of housing and infrastructure (IEA, 2020b), means that the sector is responsible for about 17 precent of Chinese carbon emissions (J. Chen, Li, & Li, 2021). Because of this, steel making has been identified as a priority sector in the Chinese government's decarbonisation programme.

So far, the Chinese government has not yet set any target for the steel sector to reduce steel output, but has instead focused reducing production overcapacity. From 2018 onwards, the Ministry of Industry and Information Technology (MIIT) has set 'capacity replacement' rules, stating that any new steel mill could only be built if existing capacity equal to 1.25 times the capacity of the new steel mill would be shuttered. In June of 2021, this 'capacity replacement' rule was increased to 1.5 times the capacity of the new steel mill, for key areas including Beijing, Tianjin, Hebei, the Yangtze River Delta, the Pearl River Delta, and the Fenwei plains areas (MIIT, 2021a). These areas are home to the vast majority of China's steel mills, and are simultaneously the key areas identified for air pollution control measures. The capacity replacement rule does allow new steel mills using electric arc furnaces (EAF) to be built after shuttering an equal capacity of old BF/BOF blast furnaces steel making capacity. EAF typically utilize only scrap steel as a feedstock, whereas BF/BOF steel mills are for primary steel making. While the regulation is not explicit, policy makers have explained that new hydrogen-based and non-blast furnace projects such as Corex, Finex, HIsmelt etc, will also need to comply with the capacity replacement requirement (MIIT, 2021b). Other measures include financial support for companies that shutter production capacity (MIIT, 2021b).

In January 2021, the Ministry of Industry and Information Technology (MIIT) set a development target for China's domestic steel scrap supply at 300 million tonnes by 2025, up from 260 Mt in 2020 (NDRC, 2021c). In July, the National Development and Reform Commission announced the 14th Five-Year Plan for the development of a circular economy, which further raised the target for domestic scrap supply to 320 million tonnes by 2025, raising the contribution of scrap to total crude steel production from just 10% in 2020 to 30% by 2025 (NDRC, 2021). China had introduced a ban on scrap imports in 2018, lifting the ban on steel scrap imports and allowing renewable steel imports from 2021, leaving actual scrap imports in 2021 at just 560,000 tonnes, well below the peak of 13.69 million tonnes in 2009 (MEE, NDRC et al, 2020).

A further measure to reduce the output of steel has been the introduction of a tiered electricity tariff for the steel industry, raising the cost of steel production (MIIT, 2021a). The Chinese government has also repeatedly reiterated that the steel industry will be included in the national carbon emissions trading system before 2025 (Zhong, 2022). So far, development plans for the steel sector, or hydrogen developments plans, have been quiet on the use of green steel production with hydrogen.

For the foreseeable future, emission reduction in the steel sector will mostly be determined by macro-economic policies that stimulate or cool down the construction sector, and the efforts at increasing scrap steel use. For 2022, iron ore demand is largely decided by authorities' policy towards steel output controls. The expectation is that iron ore imports will continue to decline to around 1.08 billion tonnes in 2022 on falling steel production and increasing usage of steel scrap (M. Zhang & Patton, 2022).

## 4.11 Energy use in buildings: avoiding a new urban-rural divide

Energy use in buildings is becoming increasingly important in China, where the intensity of energy use is still relatively low compared to other developed economies. As living standards and industrial services increase, there is still significant scope for rising energy consumption in building operations. Primary energy consumption in China's building sector was 1,123 Mt in 2018, accounting for approximately 20% of all commercial energy consumption, and total carbon emissions associated with building energy use were approximately 2.2 billion tonnes of $CO_2$ (IEA, 2021). China's 13th Five-Year Plan for building energy efficiency describes its plans and targets for building energy consumption(Ministry of Housing and Urban-Rural Development, 2017), including improving building energy efficiency by 20% by 2020 and retrofitting 500 million existing urban buildings, and in 2021 the Outline of China's 14th Five-Year Plan and Vision 2035 proposes to carry out near-zero energy buildings (NDRC, 2021a). However, although building energy efficiency is considered an important component of the energy revolution and climate change mitigation, detailed medium- and long-term targets are still lacking (S. Guo et al., 2021).

With increasing urbanisation, improved quality of life and the fight against air pollution, China also faces the combined challenge of providing modern clean heating its citizens. For space heating solutions, it is currently common to rely on coal-based district heating in urban areas in northern China, and in urban areas in southern China, distributed heating solutions are used. In rural areas, decentralised coal and biomass stoves are still commonly used. Ground source heat pumps are being installed on a large scale as a renewable building heating solution (Hu et al., 2017). The floor area of buildings heated by ground source heat pumps has increased significantly in the last decade. Air source heat pumps are also being promoted in rural areas in northern China as part of coal to clean heating projects. Solar and electric water heaters are widely used in northern China to supply domestic hot water, and gas water heaters are widely used in southern China. A range of policies have encouraged clean fossil fuel district heating in northern China. National development plans are also supporting and subsidising renewable heating technologies such as heat pumps. From a techno-economic and environmental perspective, different building heating technologies have their own advantages and disadvantages. The choice of building heating solutions for different geographical locations in China is strongly influenced by spatial parameters such as local climatic conditions, population distribution, and natural resource availability (Su et al., 2018).

Over the past three decades, the Chinese government has been making various efforts to improve rural electrification in terms of policy and financing. As a result, significant achievements have been made in this area, with rural electrification rates exceeding 99% and production and domestic electricity needs largely being met. As a result of electrification, the economic and social, infrastructural and ecological environment in rural areas has been significantly improved. At the same time, the gap in electricity facilities between urban and rural areas has also been narrowed. China then had to establish a sound institutional framework, financing policies and vibrant county-level electricity supply enterprises to provide the growing residential energy use in rural areas (Luo & Guo, 2013). The extension of the grid to remote areas has previously been limited due to the complex topography of construction and large investments. The rapid development of residential-based decentralised renewable energy production technologies offers an opportunity to address these challenges, with a study modelling and optimising different combinations of photovoltaic panels, wind turbines and biogas generators in a Hybrid Optimisation Model for Renewable Energy. The most cost-competitive configuration was identified, while ensuring a reliable supply of electricity to meet the residential, community, commercial and agricultural needs of the village. The results suggest that a hybrid power system consisting of solar, wind and biomass is a reliable, cost-effective and sustainable option for remote rural electrification (J. Li et al., 2020).

## 4.12 Energy storage: a lack of incentives

A robust energy storage system supports China's energy transitions. Pumped hydro energy storage and new energy storage are significant technologies and basic equipment to support new power systems. China has published the 14th five-year plan on new type energy storage (NEA & NDRC, 2022). China aims to advocate and expand grid energy storage (chemical-electric energy) broadly by 2025 and achieve full marketisation of new-type energy storage including flywheel, hydrogen and chemical energy storage (NEA & NDRC, 2022). For example, system cost of chemical-electric energy is estimated to be reduced >30% by 2025 (NEA & NDRC, 2022). Pumped hydro energy storage and new energy storage are significant technologies and basic equipment to support new power systems.

China has a total energy storage capacity of about 35 GW (30.3 GW is from pumped hydro storage) as of 2020, of which only 3.3 GW was new energy storage (China Energy Storage Alliance, 2021). China plans to have 62 gigawatts (GW) of pumped-hydro storage by 2025, and 120 GW by 2030 (National Development and Reform Commission, 2021). In 2020, energy storage-related investment in China reached around 7.4 billion RMB (1.16 billion USD). This investment comes mostly from venture capital, generation companies, grid companies, solar companies, and local governments (China Energy Storage Alliance, 2021). Solar+wind (+hydrogen), solar+wind+hydropower and solar+wind+thermal (i.e., coal and natural gas) are the three future energy storage approaches that will be adopted (NDRC & NEA, 2021; NEA & NDRC, 2022).

However, China's energy storage may lack continuous economic incentives from markets and may be greatly relied on command-and-control approaches. In 2020, generation-sited storage coupled with renewable energy accounted for 40% of the total installation of storage. Many provinces have mandated the installation of storage with renewables, requiring at least 10%-20% of generation capacity. However, these provincial policies have received criticism from industry experts, who have noted the lack of financial support for such requirements, which can add up to 8-10% to project costs (German Energy Agency, 2021).

The safety of customer-sited storage stations also came into public attention following a serious fire and explosion at a lithium-iron-phosphate (LFP) battery installation near a shopping mall in Beijing on 16 April 2021, in which three people lost their lives (Tencent, 2021). The accident may push out lower-quality players and lead to a slowdown in distributed storage installations in the near term (German Energy Agency, 2021).

## 4.13 CCUS: high cost remains the main challenge

Since climate change became a global concern, negative emission technologies have seen a boom in development, with a wide range of technological ideas and concepts being developed. To date, the feasibility of some technologies has been widely questioned, while others have developed rapidly and even been put into engineering use. To date, the mainstream negative emissions technologies include natural ecosystem-based sink mechanisms and industrial technology-based carbon capture methods, with carbon capture, utilisation and storage (CCUS) and biomass carbon capture and storage (BECCS) being the two types of negative emissions technologies considered to have the greatest potential. The IEA reports that about 45% (2.8 Gt $CO_2$) of China's existing power and industrial facilities could find suitable $CO_2$ storage within 50 km, with at least one potential site within 100 km reaching 65% (4.1 Gt $CO_2$). Therefore, it is estimated that China will contribute about a quarter of all $CO_2$ captured cumulatively globally by 2070 (IEA, 2020a). In projections of different Chinese decarbonisation trajectories, CCUS is considered for both cola and biomass fired power generation, to different extents (Figure 4).

The development of CCUS in China started later than in North America and Europe, where there are already mature applications (IRENA, 2020). However, with the successive introduction of policy support and the successful operation of a number of pilot projects, China has the engineering capacity to capture, utilise and sequester $CO_2$ on a large scale (H. J. Liu et al., 2017). In China, the National 12th Five-Year Plan for the Development of Science and Technology to Combat Climate Change lists carbon dioxide capture, utilization and storage (CCUS) technology as a key technology area for focused research and demonstration, and in 2013, China released the National 12th Five-Year Plan for the Development of Carbon Capture, Utilization and Storage (CCUS) Technology to comprehensively promote the R&D and application demonstration of CCUS technology. 'The 12th Five-Year Plan for Carbon Capture, Utilization and Storage (CCUS) Science and Technology Development' was released in 2013 to comprehensively promote the R&D and application demonstration of CCUS technology (MOST, 2013). Subsequently, the NDRC issued the Notice on Promoting Carbon Capture, Utilization and Storage Pilot Demonstration, which for the first time specified that carbon capture pilot projects would be carried out in the thermal power, coal chemical, cement and steel industries, and that relevant standards and incentive mechanisms would be studied and developed (NDRC, 2013). The importance of develop CCUS has been further noticed in 13 FYPs for Controlling Greenhouse Gas Emissions and China central government Opinions on the complete and accurate implementation of the new development concept to do a good job of carbon peaking and carbon neutral work (State Council, 2021).

In order to ensure that China achieves net zero emissions by 2060, the largest emission reductions borne by the power sector will need to be achieved by CCUS or other negative emission technologies. Therefore, the earlier CCUS is deployed in the power sector, the lower the pressure on China to reduce emissions. Modelling of different roadmaps for China's energy transition suggests that CCUS will be widely implemented in China from 2035 onwards, and that carbon pricing could improve the overall efficiency of CCUS scale deployment at the national level (H. J. Liu et al., 2017). In addition to the power sector, the storage potential of CCUS in onshore oil fields could reach 3.6 Gt, with $CO_2$ capture and storage increasing with higher carbon taxes and reaching a maximum storage at a carbon tax of US$51.47 (Fan et al., 2021).

Up to August 2019, a total of nine pure capture demonstration projects and 12 geological utilization and storage projects have been carried out in China, including 10 full-process demonstration projects. In addition, dozens of chemical and biological utilization projects have been carried out in China (J. Wang et al., 2021). China’s existing $CO_2$ capture demonstration projects are mainly in thermal power, coal chemical industry, natural gas processing and methanol, cement, fertilizer production and other industries, including pre-combustion capture, post-combustion capture and oxy-fuel combustion capture. At present, several sets of $CO_2$ capture demonstration devices above 100,000 tons have been built, of which the largest capture capacity can reach 800,000 tons/year (J. Wang et al., 2021).

The investment cost of CCUS projects is huge, and the investment amount for each project is tens of millions or even hundreds of millions. For example, the investment cost of the post-combustion capture demonstration project of China Resources Group Haifeng supercritical coal-fired power plant is 85.31 million yuan, and is about 100 million yuan for the Huaneng Shanghai Shidongkou Second Power Plant (J. Wang et al., 2021). In addition, the installation of carbon capture devices will generate additional operation and maintenance costs, and an additional 140-600 yuan per ton of $CO_2$ will be added. For example, according to the test of the Huaneng Group Shanghai Shidongkou Power Plant after installing post-combustion capture devices, the electricity price increased by nearly half, from 0.26 yuan/kWh to 0.5 yuan/kWh (J. Wang et al., 2021). Last but not least, or carbon utilization and storage, the price of captured $CO_2$ is too high and is about 650 yuan/ton, which is very uneconomical for oil companies (J. Wang et al., 2021).

## 4.14 Belt & Road: switch from fossil to renewables support

The 'Belt and Road' is a strategy for cooperation between China and related countries. The strategy involves 65 countries in East Asia, Southeast Asia, South Asia, Central Asia, Southern Europe, and East Africa. As a key part of infrastructure, electricity plays an important role in paving the way for the 'One Belt, One Road' (Feng et al., 2020). In 2015, China contributed RMB 20 billion to establish the China Climate Change South-South Cooperation Fund, proposing to assist in the construction of 10 low-carbon demonstration zones, 100 climate change mitigation and adaptation projects in developing countries, and 1,000 training places to address climate change.

While China has long maintained that it was up to the governments of countries receiving aid to decide what sort of energy projects it should build, this stance has been criticised as it led to much support for long-lived fossil infrastructure. One study notes that disclosure and transparency regarding Chinese investments is opaque (Gallagher & Qi, 2021a). There do not appear to be serious enforcement consequences, even if there is a failure to comply with host country regulations. Finally, China encourages overseas investment in clean energy and in the exploration and development of high-carbon industries, but does not specifically restrict or prohibit investment in carbon-intensive and fossil fuel industries in its overseas investments, demonstrating the discrepancy between domestic and overseas investment policies. Estimates for the period up to 2019 is that Chinese domestical investments were 77% in renewable energy projects, but that overseas investment included only 22% renewables (Larsen & Oehler, 2022).

In 2017, the Ministry of Environmental Protection and four other ministries jointly issued the "Guidance on Promoting Green "Belt and Road" Construction", advocated that enterprises prioritize the adoption of low-carbon, energy-saving, environmentally-friendly and green materials and technologies to ensure low-carbon construction and operation. In 2018 released the Belt and Road Green Investment Principles, and in 2019 launched the International Alliance for Green Development of the Belt and Road (National Development and Reform Commission Belt and Road Construction Promotion Centre, 2021). China is building low-carbon demonstration zones in Laos, Cambodia, and Seychelles, and assisting renewable energy facilities and energy-saving materials such as solar photovoltaic systems in Pakistan, Bangladesh, Iran, Chile, Uruguay, and Cuba to help provide low-carbon demonstration and technical support in countries along the "Belt and Road" (China Meteorological Administration, 2022). This seems to have had an effect: China's overseas investment in solar, hydropower and wind energy in the 'Belt and Road' scheme has surpassed fossil fuels and occupied more than half of the total investments in 2020 (Gallagher & Qi, 2021a).

Xi Jinping's 2021 announcement heralds a new direction for China's overseas infrastructure development. Against the backdrop of international capital moving away from coal power development, China's commitment could impact nearly 120 GW of pipeline coal power capacity, but a clearer timeline for implementation is needed (Gallagher & Qi, 2021b). In 2020, five ministries jointly issued "Guidance on Promoting Investment and Financing to Address Climate Change" (Ministry of Ecology and Environment, NDRC, People's Bank of China, China Banking and Insurance Regulatory Commission, & China Securities Regulatory Commission, 2020). The Ministry of Commerce and the Ministry of Ecology and Environment issued the "Working Guidelines on Green Development of Foreign Investment Cooperation" to further clarify the renewable energy cooperation policy of the "Belt and Road" and support foreign investment in solar, wind and other clean energy sectors to build a clean, low-carbon, safe and efficient energy system (Ministry of Commerce & MEE, 2021). In late November, at the 2021 "One Belt, One Road" Clean Energy Development Forum, Ding Zhongli, Vice Chairman of the Standing Committee of the National People's Congress, pointed out that we should participate in international energy cooperation in all aspects through the "One Belt, One Road", explore new models for the development of clean energy industry, and provide solutions for the world energy revolution and climate change. Jointly solving the challenges of green development and providing Chinese solutions for the world energy revolution and climate change (China Development, 2021). Some reports summarize the development of green projects based on the analysis of Belt and Road construction projects, emphasizing the promotion of green technology applications, designing construction solutions according to local conditions, using sustainable financing, promoting employment and industrial development, and developing energy conservation and emission reduction in host countries (NDRC & EFC, 2021). This demonstrates China's determination to help developing countries achieve a green energy transition through the Belt and Road.

# 5. Relevance for Australian stakeholders

How China will manage to get to net-zero emissions by 2060, including what near-term targets and policies will be enacted for key sectors, is largely still being debated by Chinese policy makers.

A number of trends are already apparent, however, and others can be expected as part of most national low carbon transition strategies. A core pillar for the short term will be decarbonisation of the power sector through increasing shares of renewables, primarily wind and solar. In China a renewed push for nuclear power, and a continued switch to natural gas also contribute to reducing emissions. Whether these will lead to reduced consumption of coal-fired power, or only to limiting its growth in the short to medium-term remains to be seen, and will depend largely on macro-economic policy including the type of industries that Beijing will see as key to economic growth.

A second pillar in most decarbonisation strategies is low-carbon mobility, and in this area China is well underway, with rapidly growing market shares of electric vehicles, and increasing levels of support for hydrogen fuel cell vehicles.

In other emissions intensive processes, the steel making industry is particularly relevant in China. Its emissions are all but guaranteed to fall over the near term, as output of steel has almost certainly peaked in 2021 as a result of post-covid stimulus, and a growing availability of steel scrap will substitute increasing volumes of demand for primary steel. The decarbonisation of other industries seems a more medium to long-term agenda for Chinese policy makers; these are only shortly referenced in any strategy plans thus far, and the production of green hydrogen, one of the key low carbon feedstocks that may help decarbonize a number of industries, is still in the pilot phase.

Lastly, negative emission technologies are a key component in a number of long-term projections of emissions in China, some of which see fairly substantial levels of coal-fired and biomass power generation even by and after 2050. These technologies are however still in a very early stage of industrial development, in China as elsewhere.

There are a number of ways in which both current and future energy, resource, and processing industries in Australia may be affected by China's low carbon transition. China's imports of Australian thermal coal will likely be impacted by China's rapidly growing output of renewable and nuclear power generation, whilst China's imports of coking coal will almost certainly fall as China starts to produce less steel, and starts to produce an increasing share from scrap. This will similarly stand to impact iron ore exports. Exports of natural gas stand to benefit from China's ongoing coal-to-gas switching, and its continued substantial use for a number of decades in most projections.

Australia has abundant and very high quality natural resource endowment for generating renewable electricity, which it could use to produce green hydrogen, as well as derived products such as green steel, methanol, fertilizer, and other products. A key consideration in this is Beijing's appetite in importing large quantities of steel or hydrogen. Its current policy strategies are clearly aimed at domestic industry formation, in particular when compared with the strategies of Korea and Japan, for example. Other resource extraction industries may benefit from the growing demand for inputs to the manufacturing of batteries, electrolysers, and other renewable energy equipment. Australian institutes and companies could further benefit from a role as knowledge provider for new and growing low carbon technology sectors, as it has done in the past in the solar PV industry.

# References

Ahlers, A. L., & Shen, Y. (2018). Breathe Easy? Local Nuances of Authoritarian Environmentalism in China's Battle against Air Pollution. *China Quarterly*, *234*(December 2017), 299–319. https://doi.org/10.1017/S0305741017001370

Australia-Korea Business Council. (2021). *Mapping the Australia-Korea Hydrogen Intersections* (Issue May).

Beijing Municipal Bureau of Economy and Information Technology. (2021). *Beijing Hydrogen Industry Development Implementation Plan (2021-2025)*.

Busch, C., Jun, M., Harvey, H., Min, H., & C, E. I. P. and T. L. L. (2021). *China's carbon neutral oportunity*. Energy Innovation: Policy and Technology.

Cao, J., Ho, M. S., Ma, R., & Teng, F. (2021). When carbon emission trading meets a regulated industry: Evidence from the electricity sector of China. *Journal of Public Economics*, *200*, 104470. https://doi.org/https://doi.org/10.1016/j.jpubeco.2021.104470

Carbon Brief. (2022). China Briefing, 3 February 2022. *Carbon Brief*.

CCCCP & SC. (2021). *Opinions of Central Committee of the Chinese Communist Party (CCCCP) and State Council (SC) on peaking emissions and achieving carbon neutrality (中共中央 国务院关于完整准确全面贯彻新发展理念做好碳达峰碳中和工作的意见)*. Central Committee of the Chinese Communist Party (CCCCP) and State Council (SC).

Chen, A. (2022). Russia, China agree 30-year gas deal via new pipeline, to settle in euros. *Reuters*.

Chen, G. (2021). *2021 Research on Hydrogen Industry in China*.

Chen, H., Geng, H. P., Ling, H. T., Peng, S., Li, N., Yu, S., & Wei, Y. M. (2020). Modeling the coal-to-gas switch potentials in the power sector: A case study of China. *Energy*, *192*, 116629. https://doi.org/10.1016/j.energy.2019.116629

Chen, J., Li, S., Li, T., Li, Y. (Agnes), Song, J., Wu, Y., & Zhu, C. (2021). *Zero-Carbon Investing: Opportunities from China's Carbon-Neutrality Goal*.

Chen, J., Li, S., & Li, Y. (2021). *Pursuing Zero-Carbon Steel in China*.

Chen, Z., Tan, Y., & Xu, J. (2022). Economic and environmental impacts of the coal-to-gas policy on households: Evidence from China. *Journal of Cleaner Production*, *341*(January), 130608. https://doi.org/10.1016/j.jclepro.2022.130608

China Business Research Institute. (2022). *2022 Research Report on China's hydrogen power industry*.

China Electricity Council. (2022). *2021 Basic power sector statistics (2021 年电力统计年快报基本数据一览表)*.

CPC Central Committee and the State Council. (2015). *Opinions of the CPC Central Committee and the State Council on further deepening the reform of the electric power system (关于进一步深化电力体制改革的若干意见)*.

CREA & GEM. (2022). *BRIEFING: Most coal power plants since 2016 entered construction in China in 2021, investment in coal-based steelmaking accelerated*.

Downie, E., & Center on Global Energy Policy, C. U. (2021). *Getting to 30-60: How china's biggest coal power, cement and steel corporations are responding to national decarbonization pledges*. Center on Global Energy Policy, Columbia University.

Eaton, E. (2021). Approaches to energy transitions: Carbon pricing, managed decline, and/or green new deal? *Geography Compass*, *15*(2), 1–11. https://doi.org/10.1111/gec3.12554

Energy Iceberg. (2019). *China Shaked up Coal-fired Power Pricing, Fundamental Shifts in Renewable Pricing?*

Energy Iceberg. (2021). *China's 2025 2030 Renewable Targets & Market Sizes*.

Fabian, N. (2015). Economics: Support low-carbon investment. *Nature News*, *519*(7541), 27.

Fan, J. L., Xu, M., Wei, S., Shen, S., Diao, Y., & Zhang, X. (2021). Carbon reduction potential of China's coal-fired power plants based on a CCUS source-sink matching model. *Resources, Conservation and Recycling*, *168*(June 2020), 105320. https://doi.org/10.1016/j.resconrec.2020.105320

Feng, T., Gong, X., Guo, Y., Yang, Y., Pan, B., Li, S., & Dong, J. (2020). Electricity cooperation strategy between China and ASEAN countries under 'The Belt and road.' *Energy Strategy Reviews*, *30*, 100512. https://doi.org/https://doi.org/10.1016/j.esr.2020.100512

Gallagher, K. S., & Qi, Q. (2021a). Chinese Overseas Investment Policy: Implications for Climate Change. *Global Policy*, *12*(3), 260–272. https://doi.org/https://doi.org/10.1111/1758-5899.12952

Gallagher, K. S., & Qi, Q. (2021b). Chinese Overseas Investment Policy: Implications for Climate Change. *Global Policy*, *12*(3), 260–272. https://doi.org/https://doi.org/10.1111/1758-5899.12952

German Energy Agency, & (BMWi), S.-G. E. T. P. commissioned by the G. F. M. for E. A. and E. (2021). *China Energy Transition Status Report 2021*. Sino-German Energy Transition Project commissioned by the German Federal Ministry for Economic Affairs and Energy (BMWi).

Gosens, J., & Jotzo, F. (2020). China's post-COVID-19 stimulus: no Green New Deal in sight. *Environmental Innovation and Societal Transitions*, *36*(C), 250–254.

Goulder, L. H., & Schein, A. R. (2013). Carbon taxes versus cap and trade: A critical review. *Climate Change Economics*, *4*(3), 1–28. https://doi.org/10.1142/S2010007813500103

Graham, P., Hayward, J., Foster, J., & Havas, L. (2020). *GenCost 2020-21. Consultation Draft. CSIRO*. *December*, 81.

Guo, H., Davidson, M. R., Chen, Q., Zhang, D., Jiang, N., Xia, Q., Kang, C., & Zhang, X. (2020). Power market reform in China: Motivations, progress, and recommendations. *Energy Policy*, *145*, 111717. https://doi.org/10.1016/J.ENPOL.2020.111717

Guo, S., Yan, D., Hu, S., & Zhang, Y. (2021). Modelling building energy consumption in China under different future scenarios. *Energy*, *214*, 119063. https://doi.org/10.1016/j.energy.2020.119063

He, G., Lin, J., Zhang, Y., Zhang, W., Larangeira, G., Zhang, C., Peng, W., Liu, M., & Yang, F. (2020). Enabling a Rapid and Just Transition away from Coal in China. *One Earth*, *3*(2), 187–194. https://doi.org/https://doi.org/10.1016/j.oneear.2020.07.012

Heggelund, G. M. (2021). China's climate and energy policy: at a turning point? *International Environmental Agreements: Politics, Law and Economics*, *21*(1), 9–23. https://doi.org/10.1007/s10784-021-09528-5

Heudé, W. L., Chailloux, M., & Jardi, X. (2021). *A Carbon Border Adjustment Mechanism for the European Union*. *280*, 1–12.

Hu, S., Yan, D., Guo, S., Cui, Y., & Dong, B. (2017). A survey on energy consumption and energy usage behavior of households and residential building in urban China. *Energy and Buildings*, *148*(2017), 366–378. https://doi.org/10.1016/j.enbuild.2017.03.064

ICCSD. (2022). *China's Long-Term Low-Carbon Development Strategies and Pathways: Comprehensive Report*. Springer. https://doi.org/https://doi.org/10.1007/978-981-16-2524-4

IEA. (2018). *Power Sector Reform in China*.

IEA. (2020a). Energy Technology Perspectives 2020 - Special Report on Carbon Capture Utilisation and Storage. *Energy Technology Perspectives 2020 - Special Report on Carbon Capture Utilisation and Storage*. https://doi.org/10.1787/208b66f4-en

IEA. (2020b). *Iron and Steel Technology Roadmap*.

IEA. (2021). *World Energy Outlook 2021*.

International Energy Agency. (2021). *An Energy Sector Roadmap to Carbon Neutrality in China*. International Energy Agency.

IRENA. (2020). Global Renewables Outlook: Energy transformation 2050. In *Abu Dhabi: International Renewable Energy Agency*. https://www.irena.org/publications/2020/Apr/Global-Renewables-Outlook-2020

Jia, Z., & Lin, B. (2021). How to achieve the first step of the carbon-neutrality 2060 target in China: The coal substitution perspective. *Energy*, *233*, 121179. https://doi.org/10.1016/j.energy.2021.121179

Kahrl, F., Chen, Z., Dai, F., Gordon, J., Perron, J., & California-China Climate Institute, U. of C. (2021). *Peaking by 2025: Aligning Climate and Energy Goals in China's 14th Five-Year Plan*. UC Berkeley's School of Law.

Khanna, N., Zhou, N., Price, L., & California-China Climate Institute, U. of C. (2021). *Pathways toward carbon neutrality: A review of recent studies on mid-century emissions transition scenarios fro China*. California-China Climate Institute, University of California.

Kurmelovs, R. (2022). *'Just a new fossil fuel industry': Australia to send first shipment of liquefied hydrogen to Japan*.

Larsen, M. L., & Oehler, L. (2022). Clean at home, polluting abroad: the role of the Chinese financial system's differential treatment of state-owned and private enterprises. *Climate Policy*, 1–14. https://doi.org/10.1080/14693062.2022.2040409

Lee, A. (2022). China sets 'reasonable' price range for thermal coal, cites 'lessons' from recent power crunches. *SCMP*.

Lei, N., Chen, L., Sun, C., & Tao, Y. (2018). Electricity market creation in China: Policy options from political economics perspective. *Sustainability (Switzerland)*, *10*(5), 1–15. https://doi.org/10.3390/su10051481

Li, J., Liu, P., & Li, Z. (2020). Optimal design and techno-economic analysis of a solar-wind-biomass off-grid hybrid power system for remote rural electrification: A case study of west China. *Energy*, *208*, 118387. https://doi.org/10.1016/j.energy.2020.118387

Li, Y., & Taghizadeh-Hesary, F. (2022a). The economic feasibility of green hydrogen and fuel cell electric vehicles for road transport in China. *Energy Policy*, *160*(November 2021), 112703. https://doi.org/10.1016/j.enpol.2021.112703

Li, Y., & Taghizadeh-Hesary, F. (2022b). The economic feasibility of green hydrogen and fuel cell electric vehicles for road transport in China. *Energy Policy*, *160*(October 2021), 112703. https://doi.org/10.1016/j.enpol.2021.112703

Liao, Z., & Yao, Q. (2022). Flexibility is needed in China's national carbon market. *Nature Climate Change*, *12*(July 2021), 2021–2022. https://doi.org/10.1038/s41558-021-01273-6

Lin, J., Kahrl, F., Yuan, J., Liu, X., & Zhang, W. (2019). Challenges and strategies for electricity market transition in China. *Energy Policy*, *133*(July), 110899. https://doi.org/10.1016/j.enpol.2019.110899

Lin, Y., Yang, H., Ma, L., Li, Z., & Ni, W. (2021). Low-carbon development for the iron and steel industry in china and the world: Status quo, future vision, and key actions. *Sustainability (Switzerland)*, *13*(22). https://doi.org/10.3390/su132212548

Liu, C., Zhu, B., Ni, J., & Wei, C. (2021). Residential coal-switch policy in China: Development, achievement, and challenge. *Energy Policy*, *151*(59), 112165. https://doi.org/10.1016/j.enpol.2021.112165

Liu, H. J., Were, P., Li, Q., Gou, Y., & Hou, Z. (2017). Worldwide status of CCUS technologies and their development and challenges in China. *Geofluids*, *2017*. https://doi.org/10.1155/2017/6126505

Liu, Z., Deng, Z., He, G., Wang, H., Zhang, X., Lin, J., Qi, Y., & Liang, X. (2022). Challenges and opportunities for carbon neutrality in China. *Nature Reviews Earth & Environment*, *3*(2), 141–155. https://doi.org/10.1038/s43017-021-00244-x

Luo, G. L., & Guo, Y. W. (2013). Rural electrification in China: A policy and institutional analysis. *Renewable and Sustainable Energy Reviews*, *23*, 320–329. https://doi.org/10.1016/j.rser.2013.02.040

Mathieu, C., Barichella, A., De Perthuis, C., Nagashima, M., & Tu, K. J. (2021). *Can the Biggest Emitters Set Up a Climate Club? A Review of International Carbon Pricing Debates* (Issue June).

McGrath, G. (2021). *Electric power sector CO2 emissions drop as generation mix shifts from coal to natural gas*.

MIIT. (2021a). *Implementation Measures for Capacity Replacement in the Iron and Steel Industry (钢铁行业产能置换实施办法)*.

MIIT. (2021b). *Interpretation of "Implementation Measures for Capacity Replacement in Iron and Steel Industry" (《钢铁行业产能置换实施办法》解读)*.

Ministry of Housing and Urban-Rural Development. (2017). Thirteenth Five-year plan on building energy conservation and green buildings. *Http://Www.Mohurd.Gov.Cn/Wjfb/201703/W020170314100832.Pdf*.

Ministry of Transport. (2021). *Fourth five-year plan of green transport development*.

MoF, NDRC & NEA. (2020). *Opinions on promoting the healthy development of non-hydro renewable power generation (关于促进非水可再生能源发电健康发展的若干意见)*. Ministry of Fiance (MoF), National Development and Reform Commission (NDRC), and National Energy Agency (NEA).

MoF et al. (2020). *Notice on launching demonstration applications of fuel cell vehicles*.

Morton, A. (2018). *"Problem in waiting": why natural gas will wipe out Australia's emissions gains*.

Myllyvirta, L., Zhang, S., & Shen, X. (2020). Analysis: Will China build hundreds of new coal plants in the 2020s? *Carbon Brief2*.

National People's Congress of the P.R. China. (2022). *Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and Vision 2035 of the People's Republic of China [Original in Chinese]*.

NBS. (n.d.). *Industrial added value increased by 4.3% in December 2021 (2021 年 12 月份规模以上工业增加值增长 4.3%)*.

NDRC. (2012a). *12th Five Year Plan - Development of Coal Industry*. http://zfxxgk.nea.gov.cn/auto85/201203/t20120322_1456.htm

NDRC. (2012b). *12th Five Year Plan for renewable energy (original in Chinese)*.

NDRC. (2013). *The Twelfth Five-year plan for Energy Development*.

NDRC. (2016a). *13th FYP development plan for renewable energy, translation available via http://chinaenergyportal.org/en/13th-fyp-development-plan-renewable-energy/*.

NDRC. (2016b). *Thirteenth Five-year Plan on Energy Development*. National Development and Reform Commission of People's Republic of China.

NDRC. (2018). *Notice on measures to expand inter-provincial power transactions to reduce general industrial and commercial electricity prices (关于利用扩大跨省区电力交易规模等措施降低一般工商业电价有关事项的通知)*.

NDRC. (2019). *Notice on improving the wind power Feed-in tariff policy [Translated from Chinese]*.

NDRC. (2021a). *Fourth Five-Year Plan of Social and Economic Development of People's Republic of China*. National Development and Reform Commission(NDRC), State Council.

NDRC. (2021b). *Notice on further deepening the market-oriented reform of pricing of coal-fired power generation (关于进一步深化燃煤发电上网电价市场化改革的通知)*.

NDRC. (2021c). *The 14th Five-Year Plan for development of the Circular Economy ("十四五"循环经济发展规划)*.

NDRC. (2022). *NDRC notices 2022 no. 255, 256, and 267 approving coal mines in Yuheng, Shaanxi and Nalinhe, Inner Mongolia*.

NDRC & CNREC. (2017). *China Renewable Energy Outlook 2017*.

NDRC & CNREC. (2018). *China Renewable Energy Outlook 2018*.

NDRC & EFC. (2021). Construction and Application of the Green B&R Project Case Library. *RTI Press*, *August*.

NDRC & NEA. (2016a). *13th Five Year Plan - Development of Coal Industry*.

NDRC & NEA. (2016b). *13th Five Year Plan for the electricity sector, available via http://chinaenergyportal.org/en/13th-fyp-for-the-electricity-sector-full-text/*.

NDRC & NEA. (2016c). *Basic rules for intermediate and long term electricity transactions (Trial) (关于印发《电力中长期交易基本规则（暂行）》的通知)*.

NDRC & NEA. (2017a). *Notice on carrying out electricity spot market pilot projects (关于开展电力现货市场建设试点工作的通知)*.

NDRC & NEA. (2017b). *Orderly opening up of electricity production and consumption planning (关于有序放开发用电计划的通知)*.

NDRC & NEA. (2021). *The National coal power unit transformation and upgrading notice (全国煤电机组改造升级实施方案)*.

NDRC & NEA. (2022a). *Guiding opinions on accelerating the construction of a national unified electricity market (关于加快建设全国统一电力市场体系的指导意见)*.

NDRC & NEA. (2022b). *Opinions on Improving the Institutional Mechanism and Policy Measures for Energy Green and Low-Carbon Transformation (关于完善能源绿色低碳转型体制机制和政策措施的意见)*.

NDRC & NEA, & Agency, N. D. and R. C. & N. E. (2021). *Notice on Transformation and Upgrading of National Coal-fired Power Units (国家发展改革委 国家能源局关于开展 全国煤电机组改造升级的通知)*. National Development and Reform Comission (NDRC) & National Energy Agency (NEA).

NEA& NDRC. (2022). *Opinion on low-carbon and green transitions (关于完善能源 绿色低碳转型体制机制和政策措施的意见)*. National Energy Agency & National Development and Revolution Commission (NEA& NDRC).

NEA. (2020). *Explanation with the 'Circular on 2020 provincial-level renewable electricity quota (《国家发展改革委国家能源局关于印发各省级行政区域 2020 年可再生能源电力消纳责任权重的通知》政策解读)*. National Energy Agency (NEA).

NEA. (2021a). *China Natural Gas Development Report (2021)*.

NEA. (2021b). *Letter on soliciting proposals for the weight of responsibility for renewable energy power consumption in 2021 and the expected goals for 2022-2030(国家能源局关于征求 2021 年可再生能源电力消纳责任权重和 2022—2030 年预期目标建议的函)*.

NEA. (2022a). *Actively promote and explan nuclear energy (积极推进和拓展核能在供暖、供汽、海水淡化等领域的综合利用)*. National Energy Agency (NEA).

NEA. (2022b). *Addition of over 100000 MW of solar and wind installed capacity in 2021 (2021 年我国风电光伏发电新增装机超 1 亿千瓦)*. National Energy Agency (NEA).

NEA. (2022c). *Answers to coal-fired industry's high-quality development (《关于"碳中和"目标下煤电产业高质量发展的提案》)*. National Energy Agency(NEA).

NEA. (2022d). *Increass cross-provincial electricity transmission and support renewables development (关于政协第十三届全国委员会第四次会议 第 0229 号（工交邮电类 17 号）提案答复的函)*.

NEA. (2022e). *NEA: In principle, no new coal power projects purely for power generation will be built*.

People's Daily. (2022). Li Keqiang presided over an executive meeting of the State Council [Original in Chinese]. *People's Daily*.

People's Government of Inner Mongolia Autonomous Region. (2022). *Opinions on promoting the high-quality development of the hydrogen energy industry (关于促进氢能产业高质量发展的意见)*.

People's Government of Shandong. (2020). *Shandong Hydrogen Industry Mid-term and long-term development plan (2020-2030)*.

REN21. (2021). *Renewabless 2021: Global Status Report*. REN21.

Reuters. (2021). *China to allow coal-fired power prices to fluctuate more - state media*.

Roy, B., & Schaffartzik, A. (2021). Talk renewables, walk coal: The paradox of India's energy transition. *Ecological Economics*, *180*(February 2020), 106871. https://doi.org/10.1016/j.ecolecon.2020.106871

S&P Global. (2020). *Weakness in China's thermal coal prices may prompt government action: sources*.

Safari, A., Das, N., Langhelle, O., Roy, J., & Assadi, M. (2019). Natural gas: A transition fuel for sustainable energy system transformation? *Energy Science & Engineering*, *7*(4), 1075–1094. https://doi.org/https://doi.org/10.1002/ese3.380

Slater, H., Shu, W., Boer, D. De, & Guoqiang, Q. (2022). *Carbon Pricing Survey 2021*. *January*.

State Council. (2013). *12th FYP development plan for energy*.

State Council. (2020). *Notice of the General Office of the State Council on Printing and Distributing the New Energy Vehicle Industry Development Plan (2021-2035) (国务院办公厅关于印发新能源汽车产业 发展规划（2021—2035 年）的通知)*.

State Council. (2021a). *China's policies and actions to climate change* . State Council of People's Republic of China .

State Council. (2021b). *The 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and Outline of the Vision for 2035 (中华人民共和国国民经济和社会发展第十四个五年规划和 2035 年远景目标纲要)*.

State council, & Council, S. (2021). *Action plan of peaking carbon emissions before 2030 (国务院关于印发 2030 年前碳达峰行动方案的通知)*.

Su, C., Madani, H., & Palm, B. (2018). Heating solutions for residential buildings in China: Current status and future outlook. *Energy Conversion and Management*, *177*(October), 493–510. https://doi.org/10.1016/j.enconman.2018.10.005

The People's Government of Haiyang. (2022). *Municipal Nuclear Power Industrial Park: Building a tens of billions of new energy industrial clusters (市核电工业园区：打造百亿级新能源产业集群)*.

The People's Government of Sichuan Province. (2022). *Sichuan Provincial 14th Five-Year Plan of Energy Development*.

The People's Republic of China. (2021). *China's Achievements, New Goals and New Measures for Nationally Determined Contributions*. 1–62. https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/China First/China's Achievements, New Goals and New Measures for Nationally Determined Contributions.pdf

Wang, F., Harindintwali, J. D., Yuan, Z., Wang, M., Wang, F., Li, S., Yin, Z., Huang, L., Fu, Y., Li, L., Chang, S. X., Zhang, L., Rinklebe, J., Yuan, Z., Zhu, Q., Xiang, L., Tsang, D. C. W., Xu, L., Jiang, X., … Chen, J. M. (2021). Technologies and perspectives for achieving carbon neutrality. *The Innovation*, 100180. https://doi.org/https://doi.org/10.1016/j.xinn.2021.100180

Wang, J., Long, Y., Song, W., & Yang, P. (2021). *Development status and application prospect of carbon capture, utilization and storage (CCUS) technology*.

Wang, T., Jiang, Z., Zhao, B., Gu, Y., Liou, K.-N., Kalandiyur, N., Zhang, D., & Zhu, Y. (2020). Health co-benefits of achieving sustainable net-zero greenhouse gas emissions in California. *Nature Sustainability*, *3*(8), 597–605. https://doi.org/10.1038/s41893-020-0520-y

West, J. J., Smith, S. J., Silva, R. A., Naik, V., Zhang, Y., Adelman, Z., Fry, M. M., Anenberg, S., Horowitz, L. W., & Lamarque, J.-F. (2013). Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. *Nature Climate Change*, *3*(10), 885–889.

White, E., & Lockett, H. (2022). China orders coal miners to boost output to counter energy crunch. *Financial Times*.

WNA. (2022). *Nuclear Power in China*.

Xinhua News Agency. (2021). *During the "14th Five-Year Plan" period, China's renewable energy development will enter a new stage ()"十四五"时期我国可再生能源发展将进入新阶段*.

Xinhua News Agency. (2022). *Xi Jinping presided over the 36th collective study of the Political Bureau of the CPC Central Committee and delivered an important speech (习近平主持中共中央政治局第三十六次集体学习并发表重要讲话_*.

Xu, H., Tang, A., & Pittock, J. (2021). The dark side of ambition: side-effects of China's climate policy. *Environmental Research Letters*, *16*, 111001.

Xu, M., & Singh, S. (2021). *China liberalises coal-fired power pricing to tackle energy crisis*.

Xu, Y., & Salem, S. (2021a). Explosive behaviors in Chinese carbon markets: are there price bubbles in eight pilots? *Renewable and Sustainable Energy Reviews*, *145*(March), 111089. https://doi.org/10.1016/j.rser.2021.111089

Xu, Y., & Salem, S. (2021b). Explosive behaviors in Chinese carbon markets: are there price bubbles in eight pilots? *Renewable and Sustainable Energy Reviews*, *145*(October 2020), 111089. https://doi.org/10.1016/j.rser.2021.111089

Xue, Y. (2022). *China to remain renewable energy leader with strong capacity growth in 2022, despite subsidies phase-out*.

Yan, J., & Su, B. (2020). What drive the changes in China's energy consumption and intensity during 12th Five-Year Plan period? *Energy Policy*, *140*(March), 111383. https://doi.org/10.1016/j.enpol.2020.111383

Yang, D. xiao, Jing, Y. qiang, Wang, C., Nie, P. yan, & Sun, P. (2021). Analysis of renewable energy subsidy in China under uncertainty: Feed-in tariff vs. renewable portfolio standard. *Energy Strategy Reviews*, *34*, 100628. https://doi.org/10.1016/j.esr.2021.100628

Yi, S. (2021). *China to stop building new coal power projects overseas*.

Yin, G., Li, B., Fedorova, N., Hidalgo-Gonzalez, P., Kammen, D. M., & Duan, M. (2021). Orderly retire China's coal-fired power capacity via capacity payments to support renewable energy expansion. In *iScience* (Vol. 24, Issue 11). https://doi.org/10.1016/j.isci.2021.103287

Yu, S., Yarlagadda, B., Siegel, J. E., Zhou, S., & Kim, S. (2020). The role of nuclear in China's energy future: Insights from integrated assessment. *ENERGY POLICY*, *139*, 111344. https://doi.org/https://doi.org/10.1016/j.enpol.2020.111344

Zeng, N., Jiang, K., Han, P., Hausfather, Z., Cao, J., Kirk-Davidoff, D., Ali, S., & Zhou, S. (2022). The Chinese Carbon-Neutral Goal: Challenges and Prospects. *Advances in Atmospheric Sciences*. https://doi.org/10.1007/s00376-021-1313-6

Zhang, M., & Patton, D. (2022). *China 2021 iron ore imports retreat from record on steel curbs*.

Zhang, S., & Chen, W. (2022). Assessing the energy transition in China towards carbon neutrality with a probabilistic framework. *Nature Communications*, *13*(1), 87. https://doi.org/10.1038/s41467-021-27671-0

Zhang, X. (2021). The Development Trend of and Suggestions for China's Hydrogen Energy Industry. *Engineering*, *7*(6), 719–721. https://doi.org/10.1016/j.eng.2021.04.012

Zhao, Y. (2021). Carbon neutrality goal can save China $134 trillion by 2100: Study. *The Global Times*.

Zhu, C., & Jiayin, S. (2020). Renewable energy procurement comes to China. *PV Magazine*.