CICC Research, CICC Global Institute

Guidebook to Carbon Neutrality in China

Macro and Industry Trends under New Constraints

OPEN ACCESS

Springer

Guidebook to Carbon Neutrality in China

CICC Research, CICC Global Institute

Guidebook to Carbon Neutrality in China

Macro and Industry Trends under New Constraints

Springer

CICC Research, CICC Global Institute
Beijing, China

CICC

ISBN 978-981-16-9023-5 ISBN 978-981-16-9024-2 (eBook)
https://doi.org/10.1007/978-981-16-9024-2

Translation from the Chinese language edition: 碳中和经济学 by 中金公司研究部，中金研究院, © 中信出版集团 2021. Published by 中信出版集团. All Rights Reserved.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Foreword

At the UN General Assembly session held in September 2020, Chinese President Xi Jinping announced China's solemn pledge on carbon neutrality and carbon emission peak. In December 2020, President Xi went on to highlight a number of aggregate indicators to show China's further commitment to the fight against climate change at the Climate Ambition Summit. At the recent Ninth Meeting of the Central Committee for Financial and Economic Affairs, policymakers discussed fundamental ideas and key measures to accomplish the country's targets on carbon neutrality and carbon emission peak. To implement and achieve such a profound goal requires extensive efforts from both the regulators and the market. Recently, China International Capital Corporation Limited (CICC) has published *Guidebook to Carbon Neutrality in China: Macro and Industry Trends under New Constraints*, a comprehensive and informative work that serves as a good lead in the research on carbon neutrality and carbon emission peak. I am confident it will become a highly influential piece of work. That said, I think the research on carbon neutrality and carbon emission peak is still in its early stage. Many issues in this field remain controversial and require further in-depth analysis.

Peak Volume of Carbon Emissions: Careful Estimation is Essential

CICC's work endeavors to derive an exact number for China's peak carbon emissions and draw a clearer picture of the pathway to achieve this goal in the next 10 years through analysis of aggregate targets. While this is quite important, it is also worth noting that part of the basic data for China in this area remains unavailable. For instance, China's carbon emission intensity in 2030 should be 65% lower than the level in 2005 so that the country could achieve the target for emission peak. Naturally, we will need to know China's carbon emissions in 2005. Another example would be that China aims to increase its forest stock volume in 2030 by 6 billion cubic meters from the 2005 level. Then, we also need to know how much China's forest stock volume was in 2005 and how much carbon dioxide can be absorbed by each cubic meter of forest stock per year. However, due to the lack of accurate official statistics from government agencies or other authoritative sources, the answers to these questions could be inconclusive and misleading. A possible explanation is the inadequacies of China's data compilation in the past, causing incomplete and inconsistent data with little verification. Another possibility is that these vague numbers provided additional room for policy maneuvering before China changed its policy stance toward climate change.

CICC Research spent a considerable amount of resources obtaining its preliminary estimate on China's peak net carbon emissions in 2030. Why didn't government agencies or relevant authorities announce this number directly? The reason is possibly the lack of accurate data of year 2005. CICC's estimate is based on official data in 2017 and government announcement that the emission intensity in 2017 was 46% lower than the 2005 level. What is the rationale for our endeavors to estimate the peak emission volume? This estimation is critical as it is vital to future plans for emission cuts, the choice of proper roadmaps, as well as the design of incentive mechanisms, notably pricing schemes. Therefore, it is quite necessary to analyze this number further.

The first issue is the measurements of data. CICC's work proposes to use emission data in 2005 as the baseline for calculation. However, the measurements of the benchmark data need clarification: Is it gross or net emissions volume? Does it include other greenhouse gases besides carbon dioxide? The data measurements also affect the total carbon emission data in 2020 that has not yet been announced, as well as the strategic roadmap of emission cuts for the next 10 years. Ensuring a unified data measurement is still a challenging job in our calculation and estimation.

The second issue is GDP comparability. China aims to reduce its carbon emission intensity in 2030 by 65% from the 2005 level. To achieve this goal, we need to know how much China's comparable GDP increased over the period of 2005–2020. In principle, calculating comparable GDP with the GDP deflator or GDP growth rate is unlikely to cause much controversy. However, we should still be cautious about the use of data. For instance, there are sometimes substantial differences within the preliminary GDP growth rate, the initial and final verified GDP growth rate, and the revised number released after the national economic census. Such differences were quite visible in GDP data for 2005, 2006, and 2007. But generally speaking, the use and comparability of historical GDP data are unlikely to face significant disputes. However, forecasts on China's average GDP growth over the next 10 years are based on assumptions, and different assumptions may result in a range of estimates. All these issues call for attention in our calculation of aggregate targets.

Apart from technical details, there are also debatable questions about the logic of the calculation. As discussed above, we may use the published data from the government to derive China's carbon emission volume in 2005 and the peak emission volume in 2030. In fact, there is a logical relationship between the emission intensity data for 2005 and 2017 and the 46% decline in emission intensity from 2005 to 2017 based on verified comparable historical GDP. In other words, knowing two of the three numbers would surely enable us to know the third. This inevitably leads to a question: Why has no one officially confirmed the 2005 data? There may be some other reasons, but it is also possible that there is no disclosure plan in the first place.

Forming a Carbon Market and Determining Carbon Price

An important view in CICC's report is that peak emissions and carbon neutrality require significant investment, and we need the carbon market to guide investment into cutting carbon emissions and eventually achieving carbon neutrality. A carbon market would provide incentives for investment from two dimensions: (1) A carbon market encourages emitters to increase current productivity or reduce unit emission within their existing capacity, which helps improve carbon balance. (2) The potential of current productivity growth or emission cut is limited as capabilities of current emission control technologies are unlikely to improve much in the near term. Therefore, we need to guide intertemporal investment to substitute high-emission activities. A carbon market can provide clear signals for market investment, especially through carbon market derivatives such as carbon futures trading and forward contracts. Thus, it can help with risk control and calculations for future investment and production. Overall, the second point of investment incentives is critically important as efforts to achieve carbon emission peak and carbon neutrality largely depend on the effective guiding of investments.

CICC estimates in its report that China's demand for green investment would total Rmb139trn by 2060, and I believe this figure is based on the 2020 value of the RMB. However, different institutions offer different estimates. In a report published in March 2021, the International Renewable Energy Agency (IRENA) estimated renewable energy investments planned globally should rise 30% to US$131trn by 2050. Given that China accounts for about one-third of the world's total carbon emissions, China alone would require approximately Rmb283trn worth of investment. Such an enormous amount of investment does not emerge out of mere persuasion. Carbon markets should play a crucial role in stimulating and guiding such investment.

There also exists some doubts concerning a few aspects of the carbon market, notably fluctuations and instability of carbon prices. One important notion of CICC's research is to compare the concept of green premium with carbon price and apply these two concepts in different scenarios in light of their respective strengths. In the meantime, we should be aware that high uncertainties in future carbon prices could be attributed to three possible reasons: (1) Investment is subject to uncertainties in technological progress and the cost-performance ratios of future technologies. As most investment projects are medium- to long-term ones, the returns and investment accountings are also subject to uncertainties. (2) To strike a balance between current economic growth and future carbon neutrality, the government may introduce transitional arrangements before the country reaches the carbon emission peak and carbon neutrality. Such transitional arragements may take many forms to reduce the addtional costs brought by the carbon trading system. In addition, the schedule of emission cuts could be front-loaded or back-loaded. As such, fluctuations in the volume of emission cuts would lead to uncertainties in the quantity of emission allowances traded in the carbon market, which affects carbon prices. (3) There are uncertainties in the government's fiscal strength and subsidy policies, which affect the formation of post-subsidy carbon prices. In our exploration of emission-cut roadmaps, we should be fully aware of these uncertainties and their impacts on carbon prices.

CICC believes that unified carbon pricing may cause problems, and differentiated carbon pricing might be the solution. The world has become a human community with a shared future. It is virtually impossible to trace all the greenhouse gases in the atmosphere back to industries responsible for the emissions. Each tonne of carbon dioxide has the same negative impact on society and the economy. Therefore, the overall cost (not marginal cost) of reducing each tonne of carbon dioxide should also be the same. Nevertheless, due to the differences in green premiums and industry characteristics, a unified policy mechanism may have varying effects across different sectors. To address such differences, the government's industrial policies and fiscal policies should treat various sectors in distinct ways, providing them with differentiated incentive mechanisms.

Priority and Structural Optimization

As China endeavors to reach carbon emission peak and carbon neutrality, the country should pay adequate attention to differences between various industries, and avoid "penny-wise, pound-foolish" actions when prioritizing its efforts. The power industry should be the top priority for emission cuts as it accounts for 52% of total emissions in China and 41% on average around the world. CICC's work calls for an increase in electrification, e.g., a shift from direct consumption of fossil fuels to electricity. Meanwhile, power plants should also switch to green power production or zero-carbon power production. Therefore, electricity's share in primary energy is set to expand substantially, and CICC expects this figure to reach 70% in 2060. Although all industries should take action to reduce emissions, their demand for emission allowances may differ from each other due to variations in their emission volumes.

President Xi Jinping stated at the Climate Ambition Summit that China would increase the share of non-fossil fuels in primary energy consumption to approximately 25% in 2030, meanwhile bringing its total installed capacity of wind and solar power to over 1.2 billion kilowatts. We also need to convert the installed capacity into annual power supply by analyzing annual average utilization hours and grid absorption capacity. A critical factor in the conversion is the annual average utilization hours for different types of power generation facilities. For those who are not familiar with the power industry, here are some approximate numbers: Annual average utilization hours are 1,500 for photovoltaic (PV) power, 2,500 for wind power, 3,500 for hydropower, 4,500–6,500 for mainly coal-fired or thermal power plants, and 7,500 for nuclear power plants. It is important to note that annual average utilization hours vary significantly across different types of power plants, and the actual numbers in

China are slightly lower. In China, the current annual average utilization hours are around 2,100 in the wind power sector and below 1,300 in the country's PV power industry (in regions with less sunlight, the number even drops below 1,000). While the international annual average utilization hours of thermal power plants could be as high as 6,000–7,000, the actual number in China is just 4,200, still less than 4,500. We should be aware of these deductions in calculation when we convert installed capacity into annual power generation volume and calculate electricity's share in primary energy. At present, some analysts are too optimistic about the prospect of emission cuts in the power industry as they have neglected technological difficulties in non-fossil electricity production, power transmission, and distribution. In fact, analysis of the power industry should cover not only power production but also power grids, transmission, and distribution. Extra attention should be paid to the relationship between installed capacity and utilization hours, and the relationship between intermittent power production, peak shaving, and energy storage.

In addition to the issues discussed above, we shall also consider the investment needed in new installed capacity. While installed cost accounts for a large proportion of total investment, it is important to note how installed cost is to be amortized into the operating cost of power supply, which is closely related to annual utilization hours and grid absorption capacity. Therefore, we should not ignore additional investment for power grid performance (line loss included), energy storage, peak shaving, power transmission, and distribution. If we only look at the installed cost, it appears to be rather encouraging as the installed cost of wind and solar power has already become lower than that of thermal and nuclear power. The installed cost of nuclear power remains the highest, but the annual utilization hours of nuclear power plants may exceed 7,000. While investment returns from coal-fired power plants have remained quite competitive, the need for substantial emission cuts may compel coal-fired power producers to invest in carbon capture and storage (CCS) equipment, substantially driving up total investment costs. Moreover, CCS equipment will incur high operating costs and raise power plants' auxiliary power consumption by roughly 20%. Since CCS technology is still immature, the country should pay extra attention to support its development. When we calculate the amount of future investment needed in the power industry, we should take all these factors into account rather than focusing only on the installed cost of alternative power generation facilities. Another important issue is the source of future returns for new investment in the power industry. As the revenue from selling electricity is not sufficient to cover the investment cost, we need supplementary returns from the carbon market (or carbon tax) to provide adequate incentives for investment in the power sector. To avoid confusion and misguidance, analysis and judgment of all these issues should be aligned with the green premium for the power industry.

A similar issue is the capacity of forest stock for carbon absorption. We lack benchmark data in this field, such as China's exact forest stock volume in 2005 and the amount of carbon dioxide each cubic meter of forest stock can absorb. As China commits to increase its forest stock volume by 6 billion cubic meters by 2030, we also need data on the species, ages, and the geographic distribution of trees to estimate the approximate number of trees to be planted each year, assess the forestation roadmap, and calculate the approximate amount of carbon dioxide can be absorbed at carbon emission peak.

Additionally, we should pay attention to the difference between domestic and international sector classification frameworks when conducting international comparison. China traditionally classified its industries into primary, secondary and tertiary sectors. China's secondary sector is a particularly large emitter of carbon dioxide and accounts for almost 70% of the country's total electricity consumption, which is quite rare around the world. In fact, China's sector classification framework for emission analysis differs from the international system, posing an obstacle to international comparison. In Europe and the US, the power generation sector is the largest carbon emitter, followed by the transportation sector, the construction material (including construction steel) sector, and heating and cooling sector. Under the European and US framework, more than 80% of issues relating to emissions reduction could be solved if we direct most of our efforts to the power, transportation, and residential sectors. Such a classification framework stresses the energy consumption and carbon emissions for residential purposes. Extensive attention should be paid to residential-related activities, such as construction, urbanization, heating, cooling, and development of certain infrastructures as they account for a fairly large proportion of total greenhouse gas emissions. On the contrary, it would be confusing and misleading if we include a major part of residential-related emissions into production-related emissions in the secondary sector.

The Use of the CGE Model

A key contribution from CICC is its emphasis on the use of the computable general equilibrium (CGE) model for policy analysis and discussion. In fact, we may adopt the CGE model to address two more important issues. First, a slightly revised CGE model can help us analyze general equilibrium with quotas. In the days before China adopted a market economy, the central government relied on administrative measures to directly assign tasks to various departments, provinces, and municipalities. However, this mechanism neither provided sufficient incentives nor allowed the market to play an adequate role. This may also lead to exaggeration of accomplishments or failure to complete assigned tasks. The model of general equilibrium with quotas can help us analyze how the overall mechanism works in a market economy with quota restrictions. It is especially useful in finding ways to avoid excessive reliance on administrative measures.

Second, as we highlighted above, the government may introduce various transitional arrangements to strike a balance between carbon emission targets and other factors such as GDP, inflation, and people's living standards. For example, the government may design various transitional arrangements to determine how fast emission allowances will be released and whether they will be sold at full prices. How to analyze and compare these arrangements? Intertemporal CGE model can solve this problem through systemic simulations. As the CGE model can take into account quotas with different designs, it enables us to analyze different transitional arrangements from multiple policy perspectives and find the optimal solution.

Emphasis on Green Governance

The international community has attached tremendous importance to green governance amid its endeavor to address climate change and pursue green development. International consensus and collaborations also need to be reflected in green governance. At present, there are still disputes on climate issues between developed and developing countries, and some specific problems remain unsolved. First, most developing countries believe that financial and technological support for emission reduction from developed countries is far from sufficient. Second, cross-border carbon emissions also raise concerns. This involves not only border adjustment tax for international trade but also carbon emissions from international flights and shipping lines. While it is relatively easy to reach a consensus on the need to control cross-border carbon emissions, it remains controversial which country should receive the tax or fee on such emissions since all countries want to pocket the money. This reflects the inadequate international consensus, which hinders international collaboration and undermines the credibility of joint global efforts to address climate change. To solve these problems, we should uphold principles of multilateralism and a human community with a shared future. The construction of the Bretton Woods system after World War II could serve as a useful reference. Bold plans and vigorous commitments to action are essential.

Sound green governance needs a solid digital foundation. We should build a green governance system that effectively enables and supports measurement, accounting, pricing, evaluation, and incentive mechanisms. This system is the key to ensuring that all organizations involved work proactively to accomplish targets on carbon emission peak and carbon neutrality. China's progress in this field is limited, and many issues are still under preliminary discussion. In this regard, we may adopt practices of the measurement, reporting, and verification (MRV) system, one of the core factors in the construction of carbon trading market.

Xiaochuan Zhou
President of China Society for Finance and Banking
Vice Chairman of the Boao Forum for Asia
Former Governor of the People's Bank of China
Beijing, China

Preface: Economics of Carbon Neutrality: Some Thoughts on the Coming Transformations

The once-in-a-century COVID-19 pandemic has compelled us to think more profoundly about the human relationship with nature, notably on the urgent need to address climate change. The Chinese government has pledged to achieve peak carbon emissions by 2030, and achieve carbon neutrality, i.e., net-zero carbon emissions, by 2060. Across the Pacific, the Biden administration has brought the US back to the Paris Agreement in January 2021. Meanwhile, the 27-member European Union has committed to increasing emission cuts before 2030 and achieving carbon neutrality by 2050. Achieving carbon neutrality requires not only coordinated efforts by government bodies and non-governmental institutions but also multilateral collaborations among countries. What kind of obstacles and challenges will we encounter on the road to carbon neutrality? What new opportunities may emerge? How will carbon neutrality impact the global economy and human society?

CICC Research and CICC Global Institute sought to answer these questions in *Guidebook to Carbon Neutrality in China: Macro and Industry Trends under New Constraints*. The work systematically analyzes the pathways for China to achieve peak carbon emissions and carbon neutrality, as well as their broader implications. It differs from our usual market research in two critical aspects: 1) The study of carbon neutrality involves many disciplines, covering economics, science, and social studies; and 2) Carbon neutrality is an unprecedented challenge without past experience as a reference for public policy, which will undoubtedly play a pivotal role. Our work represents the collaborative efforts of four macro research teams and more than twenty sector teams, with invaluable contributions from external sources.

Since its initial release, *Guidebook to Carbon Neutrality in China* has triggered extensive discussions and drawn close attention from industries, academia, and policy-making institutions both in China and around the globe. This has not only deeply inspired us, but also made us realize that the impact of carbon neutrality has expanded far beyond the financial sector and even the whole economy. In fact, carbon neutrality has become a new systemic constraint on a broad range of industries and sectors. Based on extensive discussions with various parties, we have decided to adapt the original work and publish it as a book to make it both publicly accessible and academically rigorous. We hope the book will further facilitate more extensive discussions on carbon neutrality. Since the issuance of our work on carbon neutrality, a few changes have taken place both in China and abroad. This preface will focus on seven issues in conjunction with these new developments.

Cost-Effectiveness Analysis with a Clear Objective

Since the Industrial Revolution, human activities have disrupted the delicate balance between carbon emission ("carbon source") and absorption ("carbon sink"). The consumption of fossil fuels has led to a dramatic increase in the CO_2 levels, resulting in the greenhouse effect and global warming. Most scientists agree that the warming climate over the past century is attributable to human activities. Over the past 5 decades, in particular, we have witnessed profound changes in the natural environment, including melting glaciers, rising sea levels, and collapsing ocean ecosystems. This has had domino effects on the environment, resulting in a range of consequences, from growing water shortages, spreading diseases, to extreme weather conditions such as floods, droughts, and hurricanes.

The Intergovernmental Panel on Climate Change (IPCC) predicted that the world's average temperature in 2100 will be 1.5–4.8°C higher than the level recorded prior to the Industrial Revolution. If no action is taken and the current trend continues, the impact of climate change on the economy and the society will escalate. Therefore, emissions reduction and carbon neutrality will benefit human civilization in the long run.

However, emissions reduction incurs costs and may hurt the economy in the near term. Carbon emissions stem from economic activities, and fossil fuels have played a vital role in substantially improving living standards since the Industrial Revolution. Carbon emissions can be reduced in two ways: 1) Electrification of economic activities, such as industrial production, transportation and home heating; and 2) Switching from fossil fuels for electricity generation to alternative sources (e.g. renewable energy and nuclear energy) or adopting carbon capture and storage technologies to mitigate the adverse effects of fossil fuel consumption. However, these solutions face a critical problem: Clean energy is more expensive than fossil fuels and requires new infrastructure, while the higher cost is detrimental to economic growth.

The cost-benefit analysis was an early approach to studying the economic implications of climate change and policy responses. This approach compares the long-term benefits and short-term costs of emission cuts, and offers policy proposals based on the findings. However, the monetary evaluation of long-term impacts from climate change is highly imprecise and often underestimates the benefits of controlling emissions. Therefore, government policies based on cost-benefit analysis often prove to be inadequate.

In most cases, the economic analysis only captures economic activities that involve market transactions and economic effects that can be measured by monetization. However, impacts from climate change such as rising sea levels, ocean acidification and ecological imbalances often transcend the scope of traditional economic analysis, or simply cannot be monetized. Moreover, emissions reduction incurs costs at present but delivers benefits in the future. The majority of the public including policymakers tends to pay more attention to near-term costs and impacts to the economy, but neglects the interests of future generations.

As there is growing attention around the world on climate change, a global consensus on the need to address this problem has formed. Instead of arguing whether actions need to be taken, discussions now focus more on how to effectively achieve policy targets at the lowest cost. Therefore, researchers have switched from cost-benefit analysis to cost-effectiveness analysis in order to find the most effective solution with specific action plans.

When we analyze China's emissions reduction targets, a critical issue is to estimate the peak emission volume in 2030. A high peak means the country would face relatively less pressure to curb carbon emissions over 2021–2030, but may have to work hard over 2031–2060 to bring net emissions to zero as promised. The opposite would be true if the emission peak was low. Most studies on this issue derive the peak emission target from China's actual carbon emission in 2005 and the Chinese government's pledge to reduce the country's carbon intensity (i.e. carbon emission per unit of GDP) by at least 65% over 2005–2030. In our opinion, however, it is not appropriate to set the peak emission target to a specific value. Instead, a range is more suitable for realizing China's pledge.

Although a rigid, specific target on emission peak will help enhancing emissions reduction, it poses a risk of inducing stagflation. The increase of PPI in 2021 clearly shows the emergence of such risks. Even though carbon neutrality inevitably means higher costs for the economy, we do not think it is necessary to bear the brunt of the transformation pressure in the near term. As the economic recovery from the COVID-19 pandemic is not stable enough, extra caution is needed for measures with strong supply shocks, such as production limits or business shutdowns. Instead, policymakers should pay greater attention to less costly and more efficient measures. Therefore, we believe that setting a range for the peak emission target will help improve supply elasticity and facilitate both economic growth and emissions reduction.

Following the above rationale, we estimate that China's net peak emission volume in 2030 will be between 9.9bn tonnes and 10.8bn tonnes. How to interpret this estimate? Even considering the lower limit, China's aggregate peak emission volume will still be much higher than the EU's (4.1bn tonnes) and the US's (6.1bn tonnes). Moreover, the proposed duration from China's emission peak to carbon neutrality is shorter than the EU and the US. Both point to the need to significantly reduce China's carbon emissions after the peak. Regarding the upper limit, the relatively high peak emissions seem to suggest that China does not have to substantially cut carbon emissions over 2021–2030. But an examination of the per capita emission volume reveals a different picture. We estimate China's per capita peak emission at 7.4 tonnes in 2030, well below peak volumes in the US (19.6 tonnes) and the EU (9.9 tonnes). As the low per capita peak emission leaves little room for carbon emissions over 2021–2030, we believe China will have to strictly curb emissions in this period.

Since both aggregate and per capita perspectives are essential to a complete picture of emission control, we believe China will need to work hard to significantly reduce carbon emissions both before and after the peak in 2030.

Correcting Externality: What Carbon Prices Can and Cannot Do?

The effects of global endeavors to address climate change have been rather limited and far from ideal. This poses a puzzling question: Why has climate change failed to stimulate innovations in emissions reduction while population ageing has led to the development of machines to replace humans? In our view, a key factor is the so-called "negative externality": Economic activities that emit carbon dioxide benefit individuals, but their consequences such as air pollution and climate change, are borne by the entire public. With such negative externalities, prices of goods and services in the free market are inconsistent with the public interest. For example, market prices of fossil fuels are too low and the amount consumed is rather high.

Economic activities involve several types of externalities. Most externalities, such as financial risks and soil contamination, are limited to certain areas. However, climate change is a worldwide negative externality—it affects every nation and every individual. The ongoing battle against COVID-19 is comparable to emission control. Vaccination against COVID-19 has a positive global externality, as it not only protects individuals but also helps stop virus transmission. Global herd immunity could be achieved when each country vaccinates 70%–80% of its population. However, if cross-national collaboration on vaccination failed, even 100% vaccination in a single country would be unlikely to end the pandemic, because the continuation of the pandemic in other countries may cause the virus to mutate and render existing vaccines ineffective.

However, there is a key difference between addressing climate change and the battle against COVID-19. While pandemic containment measures usually have an immediate impact, it may take decades or centuries for the results of climate efforts to be seen, and such results are extremely hard to predict. Given the length of time required to address this negative externality, there is little motivation for the private sector to participate in tackling climate change, while adjustment mechanisms in free markets are very limited. As such, correcting this negative externality is the key to achieving carbon neutrality.

To correct the negative externality, intervention from public policies is essential. A key concept here is carbon pricing that measures the social cost of carbon emissions. By requiring carbon emitters to pay for their emissions, carbon pricing transforms the social cost of emissions into emitters' costs, hence prompts them to reduce energy consumption and switch from fossil fuels to clean and renewable energy. Discussions and implementation of carbon pricing policies involve two connected yet different issues: The form and the level of carbon pricing.

In theory, carbon prices should be based on the social cost of carbon emissions. To determine a proper carbon price, we need to discount the future loss caused by carbon emissions to derive its current cost. However, it is quite difficult to forecast the impacts of climate change over decades. The choice of a proper discount rate may also cause disputes as it involves a trade-off between interests of the current generation and those of their descendants. For example, the Obama administration preferred a 3% discount rate, which implies the US is willing to pay US$0.22 at present to avoid each dollar of loss due to climate change five decades from now, or less than US$0.05 at present to avoid each dollar of loss 100 years in the future.

Nicholas Stern, a renowned professor at London School of Economics and the former Chief Economist of the World Bank, estimated carbon prices in *The Economics of Climate Change: The Stern Review*, a masterpiece released in 2006 that has received widespread attention from the international community. The discount rate adopted by Professor Stern is lower than the rate adopted by the 2018 Nobel Prize laureate William Nordhaus, which implies that Professor Stern attached a heavier weight to the interests of future generations. The carbon price derived with Professor Stern's discount rate is about US$266/tonne, well above estimates predicted by Professor Nordhaus (US$37/tonne), the Obama administration (US$42/tonne), and the Trump administration (less than US$10/tonne). Significant differences between these estimates illustrate the uncertainty and subjectivity in carbon pricing.

Carbon pricing can be implemented in two ways: Carbon tax and carbon trading price. The carbon tax is directly set by the government in areas where market-based prices for carbon emissions are missing. The carbon trading price is the price of emissions permits traded in a market established under a total emissions cap set by the government (i.e. the "cap-and-trade" system). Both carbon tax and carbon trading price have pros and cons. Advantages of imposing carbon tax include high transparency and predictability of the carbon price, which helps economic entities draw long-term plans. However, the carbon tax is not directly or stably related to the emission control target, which means the volume of emissions reduction is barely predictable under the carbon tax framework. The cost of levying carbon tax is low, as it may leverage on the existing taxation system, although the introduction of a new tax could induce issues of social resistance.

In terms of the carbon trading framework, policymakers need to develop new trading mechanisms and set a cap on the total volume of emissions permitted. As such, the volume of emissions reduction is more predictable under the framework of carbon trading than carbon tax. However, carbon trading price is less predictable as it is driven by multiple factors, such as economic cycles and technological advances. For example, the carbon trading price would decline due to the falling demand for emissions in an economic recession, but may rise due to the growing demand in an economic boom. The main problem for carbon trading lies in the inelastic supply, which means all demand-side shocks would result in price fluctuations. This may lead to excessive price volatility and significantly disrupt business plans of companies and other economic entities.

Both carbon tax and carbon trading price are valuable tools for the correction of externalities. They are not entirely incompatible with each other, and both can be effective in a well-designed framework. The main difficulty for policymakers is deciding the appropriate tax rate and the proper cap on emission permits. An excessively low tax rate and an extremely high emission cap would be ineffective in imposing adequate constraints on carbon emissions or providing sufficient incentives for emission cuts. On the other hand, the economy would face significant adverse impacts if the tax rate were too high or the emission cap were too low. As we discussed earlier, the fundamental problem still lies in the excessive uncertainties in setting a proper price for each tonne of carbon emissions.

As we have set our target for carbon neutrality, the key question at present is how to effectively achieve this target at a low cost rather than assessing the long-term consequences. How should we set a proper carbon price under the cost-effectiveness framework? When economic entities choose between fossil fuels and clean energy, they usually base their decisions on cost comparison. The carbon price that makes the cost of clean energy equal to that of fossil energy is termed the "switching price" or "parity price". When describing the roadmap for carbon neutrality, the International Energy Agency (IEA) adopted the concept of switching prices in lieu of traditional carbon prices. Another example of a switching price is the so-called "green premium", a new concept proposed by Bill Gates in his recent book *How to Avoid a Climate Disaster*.

Green Premium: A More Practical Tool for Analysis

The green premium is defined as the difference between the cost of clean (zero-emission) energy and the cost of fossil energy for a certain economic activity. A negative green premium indicates that the cost of fossil energy is higher than that of clean energy—in this scenario, economic entities have the incentive to switch to clean energy and reduce carbon emissions. The green premium and carbon pricing are compatible and connected with each other. However, the green premium has three distinct advantages over carbon pricing as an analytical tool:

(1) The concept of green premium is broader than carbon pricing. The scope of carbon pricing, such as carbon tax and carbon trading price, is rather narrow and cannot fully correct the negative externality of carbon emissions. This compels regulators to intervene by issuing public policies with a broader coverage. In contrast, the green premium provides a more comprehensive framework that encompasses not only carbon pricing but also many alternative approaches. Apart from carbon tax and carbon trading, we may also lower the green premium by increasing public expenditures on technologies and innovations. Moreover, building new infrastructure to reduce the cost of clean energy consumption and formulating green standards for various industries and products could also contribute to lowering the green premium.

(2) The green premium measures the present, while carbon pricing involves assessing future uncertainties. To determine a proper carbon price, we have

to discount the future loss caused by carbon emissions and climate change to derive its current cost. In contrast, the green premium calculates the difference between current costs of clean energy and fossil fuels, and employs the result to project possible future trends. As we have already set long-term targets for peak carbon emissions and carbon neutrality, the green premium is considered a more practical tool for analysis.

(3) The concept of carbon price is uniform, whereas green premiums have distinct structural features and vary significantly across industries due to differences in technologies, business models and public policies. Calculating green premiums across industries helps policymakers assess policy feasibility in different areas. Based on assumptions about new technologies, new business models and the threshold of economies of scale, the green premium could help us identify critical periods and indicators along the implementation path.

A key innovation of this work is to apply the concept of green premium in China. Our in-depth industry knowledge has enabled us to estimate green premiums in various sectors, and incorporate them into our analysis of carbon emissions reduction. The green premium also serves as a fundamental link to combine top-down macro analysis with bottom-up micro analysis to form a complete, systematic framework for study of carbon neutrality.

Our sector teams assessed green premiums in eight industries with high carbon emissions. Under current conditions, our estimation shows the green premium is 141% in the transportation industry (excluding transportation by passenger vehicles[1]) and 138% in the construction material industry (e.g. cement and glass). In other words, the cost of using clean and renewable energy is 1–2 times higher than the cost of fossil energy. The green premium remains positive at 3%–17% in industries with relatively mature technologies, such as papermaking, nonferrous metals, steel, passenger vehicles and electricity. These figures suggest that market prices are unable to provide sufficient incentives for a switch to clean energy in those industries that collectively account for as much as 88% of total carbon emissions in China.

We calculated each of the eight industries' share of total carbon emissions and used them as weights to derive the weighted average green premium. The result (about 35%) implies a Rmb377/tonne parity carbon price, i.e. the price that can reduce the green premium to zero. Despite conceptual differences discussed earlier, the parity price is within the estimated range of international research literature (US$37–266/tonne). Based on available data, we also calculated the eight industries' historical weighted average green premium since 2015 to compile a CICC Green Premium Index. The Index shows that the switching price for clean energy has declined remarkably in recent years, although there were significant differences between industries.

We can lower the green premium by reducing the cost of clean energy and/or raising the cost of fossil fuels. However, relying solely on the second option could cause severe adverse impacts on the economy, as it may require a dramatic increase

[1] Passenger vehicles include most cars, station wagons, and vans but exclude taxies, buses, coaches, ambulances, and all waterway/air vehicles.

in the cost of fossil fuels. In our view, the optimal solution is to reduce the cost of clean energy or energy consumption per unit of GDP, which calls for technological advances and innovations in social governance. We believe this would be a positive supply shock to the economy and may generate new opportunities.

It is worth noting that the green premium is not static: It declines along with prices of clean energy, but rises when prices of fossil fuels fall due to shrinking demand. If the current clean energy prices drop below fossil fuel prices, the result is not necessarily conducive to carbon neutrality. We should dynamically examine changes in the green premium to analyze their implications. Ultimately, we still need direct or indirect intervention from public policies to set a lower bound for fossil fuel prices and carbon prices. In general, carbon prices measure the social cost of carbon emissions, while the green premium gauges incentives for the private sector to switch to clean energy. We believe both are effective tools for analysis and policy implementation and should be compatible with and complementary to each other.

Technological Advances and Social Governance

The 2018 Nobel Prize in Economics was shared by William D. Nordhaus "for integrating climate change into long-run macroeconomic analysis" and Paul M. Romer "for integrating technological innovations into long-run macroeconomic analysis."[2] Although the sharing of the prize seems to be fortuitous, we believe the two Nobel laureates' research fields are indeed linked to each other, as technological advances are crucial for addressing climate change. Moreover, technological advancement also shows externalities—individuals bear R&D costs and risks, while the whole society benefits from R&D accomplishments. That's why the private sector's R&D spending is falling below the level required to generate social benefits.

Given the negative externality of carbon emissions and positive externality of technological advances, intervention from public policies is essential to both emission control and technological development. Over the past few years, the electricity industry has been the primary contributor to the sharp decline in China's overall green premium. However, green premiums remain high in a few industries, and existing technologies are unlikely to considerably reduce the cost of clean energy usage in the foreseeable future. Only striking innovations and technological breakthroughs can effectively lower green premiums in these sectors. For example, only expensive carbon capture technologies can sufficiently reduce emissions in several manufacturing industries, such as cement and chemicals, as electricity consumption is not the main source of carbon emissions in these industries.

In the electricity industry, the green premium has already fallen below zero for power generation. The applications of clean energy, including wind power, solar power and electric vehicles, seem to have similar attributes in the manufacturing

[2] https://www.nobelprize.org/prizes/economic-sciences/2018/summary/.

industry. Growing production volumes reduce unit costs and improve project feasibility for clean energy, demonstrating the trait of economies of scale. The Chinese government's support and subsidies for the photovoltaic (PV) industry effectively boosted the development of the industry at an early stage. As the PV industry grows, it begins to benefit from economies of scale and technological advances. Furthermore, it no longer needs favorable policies or subsidies to support its business viability. This is a typical successful example of technological advancement supported by public investment.

Innovations are important for not only natural science and technology but also social governance. The relationship between green premium and emissions reduction is not always linear due to people's habits, customs and path dependence. Carbon pricing may adversely affect the economy in the near term as the emission control target may require rather high carbon prices. Meanwhile, technological R&D faces many uncertainties. To solve these problems, social governance reforms and administrative intervention are needed to promote emissions reduction and energy conservation, including the guidance towards healthier lifestyles. For example, campaigns against wasting food may help free up some farmland for soil remediation, carbon sink, or bio-energy production.

In some sectors, the introduction of new technology products may entail a steep learning curve and economies of scale could take time to achieve. Therefore, rules and regulations are more effective tools than price-based guidance to encourage emission cuts and carbon neutrality in such sectors. Examples of such rules and regulations include detailed industrial and product standards, refined urban planning, sustainable land management, and building new infrastructure such as charging stations and more convenient public transportation systems. In addition, the development of the digital economy could also play a vital role. The application of big data, for instance, can help magnify the benefits of clean energy and reduce costs. In particular, big data is able to make the generation of wind energy and solar energy more predictable by improving management efficiency on the demand side to better match power supply with demand.

Green Finance: Correct Versus Incorrect Perceptions

To understand the financial industry's role in emissions reduction and carbon neutrality, we should analyze its relationship with the real economy in two ways: 1) Financial business results from activities in the real economy. With sufficient information, the financial system can effectively convert savings into investments. In this case, the development of the financial industry follows the steps of the real economy. 2) When the real economy cannot accomplish the effective allocation of resources, the financial industry can help remedy market failures in certain areas. A good example is the development of inclusive finance. In other words, the development of the financial industry leads the way for the real economy.

We believe green finance can contribute to emission control and carbon neutrality in both cases discussed above. In the first case, the green premium has fallen below zero, which means entities in the real economy have financial incentives to switch to green energy. Therefore, the financial industry's role is to provide financing for green projects. In the second case, the financial industry directly helps lower the green premium. Both cases have been witnessed in the financing of green projects. However, we believe the second case, in which the financial industry leads the way for the real economy, is considerably more important from the perspective of public policies.

Specifically, we believe the financial industry can play an essential role in emission control and carbon neutrality in the following three ways: Reducing the cost of financing, improving the availability of financing, and creating new trading markets. The government may intervene directly by providing favorable financing conditions, such as subsidies on loan interest rates, or specifying the range of industries eligible for loans. Development financial institutions may play key roles in the initial financing for green projects. Other approaches include balancing investors' perception of risks in green and brown projects through financial instruments. The financial industry may also create new types of trading products to improve the availability of financing for green projects.

To effectively reduce carbon emissions, it is imperative to determine key sectors to be supported by green finance and main financial instruments to be employed. We estimate that the green premium is only 17% in the electricity industry, which accounts for more than 40% of total carbon emissions. Please note that this estimate also takes the amortization of fixed costs over asset life cycles into account. If we only consider variable costs, the green premium in the electricity industry should have already become negative, which means the variable cost of clean energy is lower than that of fossil fuels. Given the electricity industry's enormous share of total emissions and the high financial feasibility of going green in this sector, we believe green finance should prioritize its support to the electricity industry and electrification in other industries.

Given the highly predictable risk-return profile of the projects we discussed above, we believe credit loans, bonds and other fixed-income instruments should be the primary means of financing. While this type of green finance can be categorized as the financial support discussed in the first case above to some extent, we believe the second case also applies here. In other words, financial institutions may help directly lower the green premium and encourage participation from the private sector by improving the availability of financing or reducing the cost of capital for the initial investment. This is especially important for low-carbon projects that require high initial investment. Considering the green energy sector is essentially a manufacturing industry and China is a large manufacturing powerhouse, we anticipate the green energy sector will have strong scale effects and spillover effects in China. As a result, green finance may help boost the overall development of the Chinese economy.

Green premiums remain relatively high in some industries, such as aviation, construction materials and chemicals, largely due to technological limitations. Carbon capture technology, for instance, is still the major solution to emissions reduction, making technological innovations and breakthroughs extremely critical to those industries. But innovations and breakthroughs take time and need financial support. A key part of the financial support is public investment in fundamental research, including fiscal and development finance from development financial institutions. On the other hand, an efficient capital market, notably the equity market, can also facilitate high-risk, high-return innovations and accelerate resource reallocation.

While the amount of green credit and green bonds has been growing rapidly in recent years, the environmental, social and governance (ESG) criteria for investments have become another popular topic. The total amount of ESG investments has exceeded US$40trn around the globe. A number of studies reveal that the average return from ESG investments is actually not lower than conventional, unrestricted investments, and the yields of green loans and bonds are also not lower than ordinary products. These findings suggest that taking social and environmental responsibility does not conflict with investors' personal interests, which appears rather counterintuitive. We propose three possible explanations for this anomaly below, and each of them has different policy implications.

(1) Financial business reflects activities in the real economy. ESG investment and traditional investment deliver the same returns because externalities of carbon emissions have already been corrected in the real economy. Although this explanation is partially justifiable, it is at least incomplete for the whole picture.
(2) Not all industries supported by green finance are really green, as the definition of green companies/industries is not clear enough. Evaluating a company's non-financial performance is not just a technical issue, but a social-ethical challenge that requires a complete system with proper standards and indicators to gauge the company's social and environmental performance. At present, we still lack widely-accepted standards on critical issues such as composition of ESG criteria and how much we can trust the ESG data provided by companies. We believe this is a key problem for the development of green finance. Therefore, a pressing issue for policymakers is to set up a better system for the formulation and evaluation of green standards, which are the fundamental infrastructure for green finance.
(3) Financial institutions and investors hold positive views on the outlook of green projects, which lower their demand for risk premiums. Optimism about new, green assets enhances the appeal of financial instruments, as they usually serve as tools for investment in new assets. On the other hand, existing assets are also an important part of our analysis because the financial industry suffers from "path dependence" as well. We believe value of existing assets related to traditional energy may be impaired during the economic transformation. This affects the financial industry as corporate borrowings related to such existing assets are listed as financial assets in the balance sheets of financial institutions.

The balance between existing and incremental assets is critical to the financial industry as it affects not only the industry's support to the green economy but also the stability of the financial system. Fundamentally, we believe this is a public policy issue that calls for actions from financial institutions. The central bank and other regulators should require financial institutions to fully disclose risks of brown project assets in a timely manner, and more stringent standards should be imposed on capital- and liquidity-coverage ratios of these assets. Regulators should also discourage financial institutions from supporting investment in high-emission assets, hence facilitate investment in green projects. In addition, the establishment of mechanisms that deal with risk exposures in brown assets will help maintain financial stability amid the green transition.

New Landscape in International Cooperation and Competition

International collaboration is essential in our battle against climate change due to the global externality of this crisis. A critical issue is how to strike a balance between equity and efficiency. In theory, the most efficient way to reduce emissions is to impose a uniform carbon price around the world and prioritize emission cuts in low-cost sectors regardless of their locations. If we adopt these measures, the volume of emission cuts would be higher in developing countries, as carbon prices are less affordable to low-income consumers in these countries. The subsequent losses in developing countries could, in theory, be covered by transfer payments from developed economies.

However, equity and efficiency are hard to balance in reality. For low-income countries, carbon emissions reduction has a large marginal impact on consumption, and fiscal transfer payments between nations are difficult to accomplish. In the near term, poverty reduction is more urgent than climate problems. In fact, developed economies are responsible for most of the carbon emissions since the Industrial Revolution, while developing countries actually suffer from the lack of energy—a key manifestation of economic poverty and development inequality. On the other hand, low-income countries should not follow the same development path adopted by advanced economies in the past due to its huge demand for resources, especially energy, that is clearly unsustainable from a global perspective.

To better understand the international cooperation and competition on climate change, we need to examine price differentials in two key areas and their significant implications:

(1) Given the income gap between developed and developing economies, the volume of emissions reduction in developing countries is more elastic to carbon prices. In other words, the same carbon price would lead to higher emission cuts in developing countries. This implies carbon prices should be lower in developing countries than in developed economies. However, the differential in carbon prices may lead to "carbon leakage", i.e. the relocation of high-emission industries to developing countries. In response to this problem, a number of developed economies are discussing a "carbon border tax". However, setting a

proper tax rate is a complex issue involving numerous uncertainties. If handled improperly, the tax could easily be turned into a tool for trade protectionism.

(2) Interest rates are higher in developing economies than in developed countries. A high discount rate means a lower present value of the future that benefits from climate improvements. For emerging markets, a high interest rate also means high returns from investment in sectors unrelated with climate change, which makes it necessary to strike a balance between investments in emission control and in other areas. Moreover, a high interest rate means there is more room for the financial sector to function, which leads to capital flows from high-income countries into low-income ones. To solve these international problems in green finance, we need bilateral and multilateral cooperation to remedy market failures. Development financial institutions may help reduce project risks and attract investment from the private sector.

In our view, international cooperation and competition to address climate change will no doubt significantly impact the existing global governance system. A major challenge for the international community is how to build a more binding mechanism than the Paris Agreement for emission control. Substantial changes in the international arena call for revamping of the governance structure of international trade and financial systems established after the Second World War, including the World Trade Organization, the International Monetary Fund and the World Bank. As a large economy, China's commitment to carbon neutrality is an important part of the global effort to address climate problems. Moreover, China should play an important role in shaping a new international governance system, including cooperation with countries along the Silk Road Economic Belt and the 21st-Century Maritime Silk Road (the Belt and Road).

Although China is at a disadvantage regarding fossil fuels due to differences in natural resource endowments, the country's strengths in manufacturing and the digital economy give it a potentially competitive edge in clean energy. We believe that international peer pressure will compel all countries to adopt similar strategies to address climate change, and emissions reduction will become a prevailing trend. Although this could be a challenge for China, we believe the country actually has a first-mover advantage in emission control and carbon neutrality.

Stagflation or New Opportunity: Thoughts About Market Economy in Reality

Addressing climate change and achieve carbon neutrality, in essence, requires the transformation of development models and economic structures through relative price changes. All measures to reduce carbon emissions, including the carbon tax, carbon trading price, administrative regulation and green finance, take effect by raising fossil fuel prices and lowering clean energy prices. Under the new growth model, clean energy will serve as the foundation for healthier lifestyles and sustainable development of human society. However, relative price change is a supply shock that causes frictions in the economy's transition from the old equilibrium to the new equilibrium.

Effects of carbon pricing are similar to the impact from shrinking oil supply: Production cost rises on the supply side and real income declines on the demand side. From a macroeconomic perspective, these are characteristics of stagflation. How strong is the pressure of stagflation? Our computable general equilibrium (CGE) model shows that whether China can achieve carbon neutrality by 2060 hinges on technological advancement, which comes at a cost. A rising carbon price could serve as an incentive for technological development, but it may undermine GDP growth and drive up other prices. Our sector studies reveal that reducing the green premium to zero at this stage would raise costs significantly in manufacturing sectors such as chemicals and construction materials.

Our structural analysis suggests that certain economic activities, technologies and even industries may be replaced by new models amid the transformation to achieve carbon neutrality. Traditional energy industries, notably the coal industry, may face severe adverse impacts. Therefore, we expect employment to decline in infrastructure, manufacturing and service sectors related to traditional energy, whereas employment will rise in clean/renewable energy industries and related sectors. As the regional distributions of fossil fuels are largely natural endowments, the transformation will inevitably vary across different regions, especially in a large economy like China. Severe negative impacts are expected in provinces and regions that produce high volumes of fossil fuels, of which the economies are usually underdeveloped. Meanwhile, prices of traditional energy may rise for some time amid the transition. We believe this will hurt low-income groups more severely than middle- to high-income groups. To address these problems in structural adjustment and income distribution, we will need effective public policies, notably fiscal policies.

From a more fundamental perspective, carbon neutrality imposes on economic activities a single quantitative constraint that affects all aspects of the economy but cannot be priced in the free market. This is an unprecedented challenge to public policies and the market economy. Policymakers are confronted with a multitude of problems that they have never encountered before: Under such rigid constraints, how do we remedy the absence of market mechanisms and avoid excessive government intervention at the same time? How to balance short-term and local interests with long-term and overall interests of the whole society? It remains highly uncertain how carbon neutrality will affect the economy and society, but the most fundamental issue is probably the impact on mainstream social thoughts and ideas. How to interpret this issue?

Looking ahead, we envisage three possible scenarios: 1) Efforts to achieve carbon neutrality are unsuccessful or fail to reach the target in time. Consequently, global climate change causes severe damage to human civilization; 2) Carbon neutrality is achieved mainly by raising the cost of energy consumption. As such, the world economy suffers from long-term stagflation; 3) Carbon neutrality is achieved thanks to technological advances and innovations in social governance under effective public policies and international cooperation. As a result, the world will shift to a new development pattern and people will enjoy a better and healthier life.

All three scenarios represent challenges to neoclassical economics, which has prevailed over the past 4 decades. As climate change's spillover effects are cross-regional and intertemporal, we doubt whether externality is an adequate supplement to basic assumptions of neoclassical economics, i.e. complete information, certainty and perfect competition. How can a single, quantitative indicator such as carbon emissions become a uniform constraint on global economic and social development? How will interactions among public policies, social governance mechanisms and market mechanisms evolve along with our process toward carbon neutrality? Perhaps only time will tell. However, the endeavor to achieve carbon neutrality will definitely lead to a deeper understanding of the difference between the neoclassical ideal market and the market in reality.

Neoclassical economics' deviation from reality calls for a close reexamination of economic thoughts and points to the necessity of returning to classical economics. Classical economists, such as Adam Smith and David Ricardo, recognized that human activities are subject to natural constraints, and emphasized political economy perspectives such as social ethics and humanities. In response to climate change, economists are compelled to reevaluate the role of nature in their analytical framework. In addition to labor and productive capital, we should also take into account natural capital such as clean water, clean air, forests, oceans, and biodiversity. As natural capital cannot be fully priced in free markets, proper public policies and social governance are essential. Meanwhile, we believe people will attach greater importance to equity in the equity-efficiency tradeoff.

The road to carbon neutrality is a long learning curve for all of us. While we have tried our best to analyze carbon neutrality in this book, we are well aware that mistakes and omissions may be inevitable. We will pay close attention to China's progress toward carbon neutrality and update our analysis and conclusions when necessary.

Wensheng Peng
Executive Dean, CICC Global Institute
Chief Economist and Head of Research Department, CICC
Beijing, China

Acknowledgments

The motivation behind this book is rooted in the endeavor to discuss the pathways of China towards carbon neutrality and the economic and industry trends under new constraints, which are of great significance to China and the world. The publication of this book would not have been possible without support from many people to whom we would like to express our sincere thanks and gratitude. We would like to extend special thanks to four macro and over twenty sector research teams of CICC Research and CICC Global Institute for their great work and effort. We are highly indebted to our translating and editing team for their dedications to translation and refining the English manuscript. We also would like to thank all of those who have made remarkable contributions to the book.

Foreword
Author: Xiaochuan Zhou
Translator: Bin Kong
Editors: Kenneth Ho, Min Zhu, Xinran Liu, Zhiyuan Li

Preface: Economics of Carbon Neutrality: Some Thoughts on Entailed Transformations
Author: Wensheng Peng
Translator: Bin Kong
Editors: Andrew Cheng, Xinran Liu, Yuwei Zhang

Chapter 1: Exploring the Road to Carbon Neutrality
Authors: Wensheng Peng, Chao Xie, Jundong Zhang, Liu Liu, Jin Li.
Translator: Jincheng Huang
Editors: Kenneth Ho, Jundong Zhang, Nanding Chen

Chapter 2: Balancing Efficiency and Fairness: Kaldor-Hicks Improvement?
Authors: Wenlang Zhang, Zhengning Liu, Qiaofeng Deng
Translator: Wendong Wang
Editors: Andrew Cheng, Enduo Xu, Nanding Chen

Chapter 3: The Capacity of Carbon Pricing Mechanism
Authors: Wensheng Peng, Chao Xie, Jin Li, Enduo Xu
Translator: Wendong Wang
Editors: Kenneth Ho, Enduo Xu, Weihan Zhang

Chapter 4: Green Finance: Clarifying Functions and Capacity
Authors: Zipeng Zhou, Shuaishuai Zhang, Zeyu Yao, Xiaoxiao Zhou, Peng Zhou, Yu Cheng
Translator: Jian Liu
Editors: Andrew Cheng, Xinran Liu, Weihan Zhang

Chapter 5: Green Technology: From Quantity to Quality
Authors: Xiaofeng Qiu, Yan Chen, Jun Liu, Zhongyang Wang
Translator: Yi Zhang
Editors: Carol Keaty, Xinran Liu, Donghua Jiao

Chapter 6: Green Energy: A New Chapter in China
Authors: Xiaofeng Qiu, Yan Chen, Jun Liu, Zhongyang Wang, Tao Zeng
Other contributors: Jiani Liu, Song Wang
Translator: Tong Sun
Editors: Michael Hoare, Zhiyuan Li, Donghua Jiao

Chapter 7: Green Manufacturing: Carbon Emissions Reduction Roadmap of Carbon Intensive Sectors
Authors: Yan Chen, Xiaofeng Qiu, Lingxin Kong, Keyue Li
Other contributors: Qing Gong, Qichao Zhao
Translators: Bo Liu, Yu Yan
Editors: Kenneth Ho, Zhiyuan Li, Xinran Liu

Chapter 8: Green Transportation: A Challenging Road to Carbon Neutrality
Authors: Xin Yang, Wenjie Zhang, Tao Zeng, Jing Chang, Zhenhao Chen, Xue Deng
Translator: Wei Lu
Editors: Andrew Cheng, Donghua Jiao, Xinran Liu

Chapter 9: Living Green: New Chapter of Consumption and Social Governance
Authors: Haiyan Guo, Junhao Fan, Wei He, Sijie Lin, Wenbo Chen
Translator: Bo Liu
Editors: Jonathan Barlow, Donghua Jiao, Zhiyuan Li

Chapter 10: Green City: Towards Low-Carbon Urban Planning and Governance
Authors: Yu Zhang, Xin Yang, Aobo Zhan, Xinhao Jiang, Pu Wang
Other contributors: Wenjie Zhang, Yuqi Zhang
Translator: Xinyue Zhang
Editors: Robert Park, Nanding Chen, Zhiyuan Li

Chapter 11: Digital Economy Goes Green: Taking Over Energy-Efficiency Management
Authors: Kai Qian, Hu Peng, Liping Zhao, Hao Chen

Translator: Yi Zhang
Editors: Wanbo Zhou, Weihan Zhang, Enduo Xu

Chapter 12: Green Investment: New Trend, New Direction
Authors: Hanfeng Wang, Hao Wang, Yue Kou
Translator: Wei Lu
Editors: Kenneth Ho, Weihan Zhang, Enduo Xu

Chapter 13: Tackling Climate Change: Global Cooperation and China's Commitment
Authors: Ting Wu, Huimin Wu
Translator: Qian Wang
Editors: Andrew Cheng, Nanding Chen, Yuwei Zhang

Contents

Chapter 1
Exploring the Road to Carbon Neutrality

Abstract How to deal with carbon emissions—a rare externality that spans a large time frame and geographical scope—is a difficult task for the world. This task is particularly challenging for China, mainly in that the country must coordinate dual objectives, including existing economic growth targets and the newly added carbon neutrality goal. Over the past 40 years of reform and opening up, China has been setting economic growth targets and striving to achieve them. In recent years, although growth targets have softened along with the secular decline in potential growth rate, economic growth remains a top priority for China, the world's largest developing country. We expect China to reach the current standard for a high-income country by the end of the 14th Five-Year Plan period, and to double its GDP or per capita income by 2035. Currently, China is adding a new constraint over the next 40 years. As the world's largest carbon emitter, China has set out a clear timetable for carbon neutrality—to reduce its carbon emission intensity in 2030 by more than 65% from the 2005 level, and reach the peak of carbon dioxide emissions by 2030 and become carbon neutral by 2060. We note that it will take 71 and 45 years, respectively, for the EU and the US to achieve the carbon neutrality goal from peak carbon emissions (reached by the EU in 1979 and by the US in 2005) to net zero emissions. China's aggressive timetable to achieve carbon neutrality within 40 years means that the country will face a much steeper slope of carbon emissions than the EU and the US. How will China strike a balance between the objectives of economic growth in the past 40 years and carbon neutrality in the next 40 years? We discuss this issue from an aggregate and a structural point of view. In our aggregate analysis, the most important task is to identify the peak of China's carbon emissions in 2030. We believe that in order to take economic growth and emission reduction into consideration, it is more appropriate to set the carbon peak target in a range to avoid rigid constraints. From a structural perspective, we discuss how China can achieve its carbon peak and neutrality goals. Under the framework of a "green premium", we come up with a preliminary idea of "technology + carbon pricing" based on the analysis of eight high-emission industries. We prove that this idea can strike a balance between the constraints of economic growth and carbon neutrality goals through general equilibrium analysis using the computable general equilibrium (CGE) model. Finally, we incorporate social governance into our analysis by discussing the meaning of a

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_1

Table 1.1 Annual and cumulative carbon emissions

Year	Indicator (bn tonnes)	EU	US	India	China
1950	Annual carbon emissions	1.3	2.5	0.06	0.08
	Cumulative carbon emissions	65.6	92	2	1.9
2019	Annual carbon emissions	2.9	5.3	2.6	10.2
	Cumulative carbon emissions	287	410.2	51.9	220

Source Our World in Data, World Bank, CICC Research

Table 1.2 Intensity of carbon emissions and emissions per capita

Year	Indicator	EU	US	India	China
1970	Carbon emission intensity (kg/USD)	0.6	0.9	0.8	4.1
	Carbon emissions per capita (tonne)	8.6	20.6	0.3	0.9
2019	Carbon emission intensity (kg/USD)	0.2	0.3	0.9	0.9
	Carbon emissions per capita (tonne)	6.6	16.1	1.9	7.1

Source Our World in Data, World Bank, CICC Research

negative green premium, and arrive at this formula: the road to carbon neutrality = technology + carbon pricing + social governance.

1.1 Seeking a Peak: 9.9–10.8bn Tonnes of Net Carbon Emissions

We examine China's carbon emission issue from a historical and a future perspective.[1] As shown in Table 1.1, while China's annual carbon emissions in 2019 were much larger than other economies, the US and the EU, which started industrialization earlier, had greater cumulative emissions.[2] Moreover, China's carbon emissions per capita were 7.1 tonnes, still less than half the US's 16.1 tonnes (see Table 1.2). Such historical perspective is very important for countries to distinguish their "common but differentiated" responsibilities when making coordinated carbon neutrality goals.

[1] For details, please refer to President Xi Jinping's explanation about the CPC Central Committee Proposals on Formulating the 14th Five-Year Plan of National Economic and Social Development and the Long-Range Objectives through 2035: During the process of soliciting opinions, some local governments and government departments proposed to clearly set a target of economic growth rate during the 14th Five-Year Plan period, and clearly set a goal of doubling GDP or per capita income by 2035. After careful research and calculations, the document drafting team believes that judging from economic development capabilities and conditions, China has the promise and potential to maintain long-term stable development, and it is entirely possible for China to reach the current high-income country standard by the end of the 14th Five-Year Plan period, and to double its economic aggregate or per capita income by 2035.

[2] Cumulative carbon emissions are calculated based on data since 1751.

However, from a future perspective, these facts are of little significance to China's achievement of its goals of carbon peak by 2030 and carbon neutrality by 2060.

Although China's carbon emission intensity has declined the fastest among major economies in the past few decades, its current carbon emission intensity is still about 5 times that of the EU and 3 times that of the US due to large differences in industrial structure. If the road to carbon peak in the next 10 years is understood as seizing the "buffer period" to catch up with the US in terms of cumulative emissions and per capita emissions, the road to carbon neutrality in the subsequent 30 years would be tremendously challenging.

More importantly, carbon peak in the US and the EU is not a target of previously decided emission constraints but a natural result of development, which means it is of little significance for referencing in China's peak setting. From our point of view, the targeting of a carbon peak by 2030 does not mean that China can emit freely in the next 10 years. Instead, as carbon neutrality has become a new constraint, the target of carbon peaking by 2030 requires that China changes its thinking from now on and take actions immediately to reach the peak as soon as possible and try its best to lower the peak. Additionally, we believe that it is more appropriate to set the target within a range instead of a specific number so as to avoid a rigid constraint in supply side. Such consideration is mainly based on the following three aspects:

First, the statistics of carbon emission are inherently uncertain and are difficult to quantify accurately. Constrained by current technological measures, the amount of greenhouse gas emissions in each country is obtained through aggregating the levels of emission in various activities multiplied by the corresponding emission factors. Such calculation results are uncertain because of inherent methods. To unify the calculation measure for all countries, Intergovernmental Panel on Climate Change (IPCC) has formulated the *Guidelines for National Greenhouse Gas Inventories*, which provides basic technical regulations and emission factor data applicable to all countries.

Nevertheless, the IPCC also emphasizes and encourages each country to take measurements and parameters that are applicable to the country-specific situation. Since it is difficult to accurately calculate the level of emission activities and emission factors, different institutions have various standards to determine localized parameters. Even different literature in major scientific journals such as *Nature* would have a difference of 10%–20% in the calculation of carbon emissions in the same country. Due to the inherent uncertainty in carbon emission calculation, it may not conform to the scientific laws to pursue an accurate target of carbon peak.

Secondly, our estimates suggest that China's net carbon emissions will range from 9.9 to 10.8bn tonnes in 2030. Looking into the future, the peak of China's carbon emissions depends on two factors. One is the GDP growth trajectory from now to 2030. According to the Outline of the 14th Five-Year Plan (FYP), we assume that GDP will double over the period of 2020–2035 and the GDP growth rate will drop at a constant rate from 6% in 2019.[3] Thus we derive the GDP CAGR over 2020–2030 at 5%. The other is the reduction in carbon emission intensity in 2030 from

[3] Here we exclude the temporary impact of the COVID-19 pandemic in 2020.

the current level. The authorities have stated that carbon emission intensity in 2030 will drop by more than 65% from the level in 2005. In recent years, the government has announced the reduction in carbon emission intensity each year from the level in 2005 (for example, the intensity in 2019 was 48.1% lower than that in 2005). The 13th and 14th FYPs clearly set a target of reducing carbon emission intensity by 18%. We assume that the 15th FYP will also target an 18% reduction. As such, we estimate that carbon emission intensity will be reduced by an average of 3.9% annually in the next 10 years, and the intensity in 2030 will decline for more than 65% from the level in 2005.

Thirdly, the risk of stagflation is looming. As a result, setting the peak target within a range would help improve supply elasticity and balance between economic growth and emission reduction. As the world's largest developing country, sustainable economic growth remains China's top priority. Meanwhile, the launch of "carbon peak in 2030, carbon neutral in 2060" suggests that the country is implementing a new constraint to the next 40 years. Before carbon neutral technologies become fully mature, the conflict between the two constraints will persist. In such a scenario, a rigid emission target would be able to help promote emission reduction, but would also easily induce stagflation.

In fact, such risk may have emerged already. The rapid increase in PPI during March and April 2021 may be partially attributed to the post-pandemic demand recovery, but what is more noteworthy is the decrease in supply elasticity under strengthened environmental constraints. This is relevant to the heavy reliance on the rigid administrative policies such as shutdowns or restricted production in certain areas. Although carbon neutrality means cost increases are inevitable, it is not necessary to cope with the transition pressures in short term.

At the current stage, in which the foundation of economic recovery is still unstable, measures with strong supply shocks such as production restriction and shutdown should be implemented with caution. Measures that come with lower social cost and higher efficiency, such as promoting inventory adjustment through incremental reforms, enlarging low-carbon and zero-carbon capacity investment to enhance high-carbon capacity replacement, and strictly controlling new-added high-carbon capacity investments, deserve more consideration. From a medium- and long-term perspective, a more important aspect of overall management is to set the peak emission target within a range to avoid overly rigid supply constraints.

Based on the above-mentioned trajectories of GDP growth and carbon emission intensity reduction in the future, we can discuss in further details the peak of carbon emissions in 2030. First, we need to solve the issue of carbon emission data. The existing carbon emission databases mainly include the China Emission Accounts and Datasets (CEADs), BP database, and official data from the Ministry of Ecology and Environment (MoEE). Since data from the MoEE is not continuous, the time-continuous CEADs and BP databases are more suitable for research (see Fig. 1.1). Carbon emissions according to the three databases (not considering carbon sinks) were 5.4, 6.1, and 5.98bn tonnes in 2005, and 9.44, 9.24, and 10.28bn tonnes in

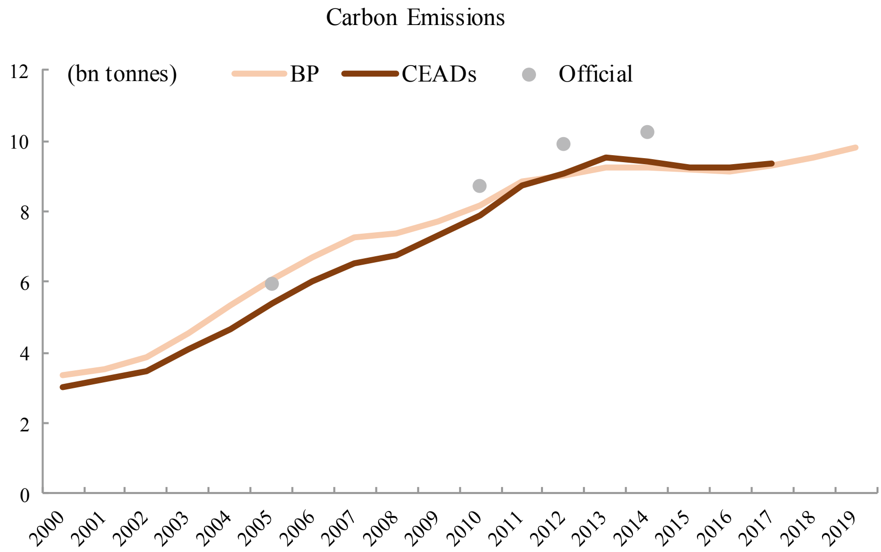


Fig. 1.1 Carbon emissions according to different databases. *Source* CEADs, BP, MoEE, CICC Research

2014.[4] Emissions in 2017 according to the CEADs and BP database were 9.34 and 9.3bn tonnes. It can be seen that the numerical difference between the CEADs and BP database has narrowed significantly in recent years. Considering that the CEADs include emission data for 29 industries and is convenient for structural analysis and CGE model simulation, we decided to use the CEADs for analysis.

In order to avoid the uncertainty caused by the large differences between early carbon emission data of different databases, we select carbon emissions in 2017 according to the CEADs (9.34bn tonnes) as the calculation benchmark. We calculate peak carbon emissions in 2030 under two scenarios of carbon emission intensity reduction: (1) carbon emission intensity reduced by 46% in 2017 (official data) and by 65% in 2030 (official target) from the level in 2005; and (2) carbon emission intensity falling by an average of 3.9% annually before emissions peak, or carbon emission intensity reduced by 66.5% in 2030 from the level in 2005. Carbon emissions in 2030 will peak at 11.7bn tonnes and 10.8bn tonnes respectively in these two scenarios. Considering that there will be 910mn tonnes of agricultural and forestry carbon sinks in 2030,[5] net emissions in 2030 will peak at 10.8bn tonnes and 9.9bn tonnes respectively in these two scenarios. Since scenario 2 is based on an additional assumption that the 15th FYP will still target an 18% reduction in carbon emission intensity, which increases the uncertainty of the calculation result, we tend to adopt the calculation result of scenario 1, i.e. a peak of 10.8bn tonnes. In addition, although

[4] Official carbon emission data is often relatively large due to more comprehensive statistics on carbon emissions during industrial production processes.

[5] According to calculations by the Institute of Climate Change and Sustainable Development of Tsinghua University; please refer to China's Long-term Low-Carbon Development Strategy and Pathway.

Table 1.3 Calculations of peak carbon emissions (net emissions) in 2030

Peak value calculation in 2030 (net emissions, bn tonnes)		
	Carbon intensity in 2030 is 65% lower than that in 2005	Reduce carbon intensity by 18% in each 5-year period
CEADs (9.3bn tonnes in 2017)	***10.8***	9.9
BP (9.8bn tonnes in 2019)	10.4	10
Official (10.3bn tonnes in 2014)	11.9	12

Source CEADs, BP, MoEE, Institute of Climate Change and Sustainable Development of Tsinghua University, CICC Research

we use the CEADs as the benchmark database, we also make same calculations based on the BP data in 2019 and the official data in 2014 (see Table 1.3), in order to assess the extent of the calculation uncertainty.

Discussion on the Uncertainty of Calculations Our calculations of peak emissions in 2030 based on emission intensity may face uncertainty in three aspects: The assumption on future GDP growth rate, the quality of historical emission data, and the understanding of the emission intensity reduction target itself.

1. The assumption on GDP growth rate is mainly based on the proposal to "double China's economic aggregate or per capita income by 2035". The uncertainty lies in the assumption that the GDP growth rate will drop at a constant rate from 2019 in the next 15 years.
2. As many studies have noticed, the quality of historical data on carbon emissions in early years is not high enough. For example, there is a controversy about the amount of China's emissions in 2005. We noticed two phenomena in the calculation process. One is that BP data and CEADs data have gradually converged over time. The other is that the officially announced emission intensity in 2017 declined 46% from the level in 2005, and the newer emission data in 2017 is less controversial. Hence, we use 2017, for which data is of higher quality, rather than 2005, for which data is more controversial, as the benchmark for calculations, to avoid the risk of errors stemming from the relatively low quality of early emission data.
3. Academically, scholars' calculations of peak carbon emissions usually refer to net emissions after deduction of carbon sinks. The CEADs and BP databases calculate gross emissions without deduction of carbon sinks. Whether the target of reducing carbon emission intensity in 2030 by 65% from the level in 2005 is based on gross emissions or net emissions does not seem to be specified. In our aforementioned calculation method, we interpret this target from the perspective of gross emissions. We first calculate peak gross emissions in 2030 at 11.7bn tonnes, then deduct carbon sinks in 2030, and derive peak net emissions in 2030 at 10.8bn tonnes, roughly between the peaks calculated by Tsinghua University and the World Resources Institute. If we interpret the target from the perspective of net emissions, we need to first convert the data on gross emissions in the

CEADs into data on net emissions based on historical carbon sinks calculated by Tsinghua University and other institutions, and then we arrive at peak net emissions of about 10.9bn tonnes in 2030, close to the calculation result based on gross emissions. Upon consultation with our utilities analysts, we tend to understand the target of emission intensity reduction from the perspective of gross emissions, which means that we estimate peak net emissions in 2030 at about 10.8bn tonnes.

In summary, even with the upper limit of 10.8bn tonnes for peak carbon emission in 2030, our estimate still suggests that China's emissions can only increase less than 10% in the next 10 years compared with the level in 2020.[6] At the same time, China's annualized real GDP growth rate needs to reach 5%. This highlights the difficulty of China's carbon peaking in the next 10 years. From the perspective of international comparison, China's peak emissions are much higher than those of the EU and the US, meaning that it is more difficult for China to achieve carbon neutrality after reaching the carbon peak. The EU reached its carbon peak in 1979, with peak emissions at about 4.1bn tonnes and peak emissions per capita at 9.9 tonnes. The US reached its carbon peak in 2005, with peak emissions at about 6.1bn tonnes and peak emissions per capita at 19.6 tonnes. According to our above calculations, China's peak emissions in 2030 will be 10.8bn tonnes and peak emissions per capita will be 7.4 tonnes. Both the EU[7] and the US[8] aim to become carbon neutral by 2050. If the stage from peak to neutrality is defined as the second half of carbon neutrality, the second half will be 71 years for the EU and 45 years for the US, but only 30 years for China. From an aggregate perspective, China will face a much steeper slope of emission reduction than the EU (see Figs. 1.2 and 1.3). How can China achieve this difficult goal? We will discuss the industry-level neutralization path from a structural perspective in the next section.

1.2 Structural Path: Analysis Based on Green Premium

After the aggregate target is determined, the next step is to explore how to achieve peak carbon emissions and become carbon neutral. There are two ways to do this: (1) reducing emissions on the demand side, or even directly curbing demand (such as power rationing); and (2) promoting clean energy, improving production technology, and developing carbon capture on the supply side. Restricting demand runs counter to the pursuit of economic growth in the past 40 years, and demand-side management such as power rationing and emission reduction promotion can only realize a (temporary) reduction in emissions but is unable to achieve carbon neutrality. The

---

[6] China's Long-term Low-Carbon Development Strategy and Pathway, Institute of Climate Change and Sustainable Development of Tsinghua University, Chinese Journal of Population Resources and Environment.

[7] https://ec.europa.eu/clima/policies/strategies/2050_en.

[8] https://joebiden.com/climate-plan/.

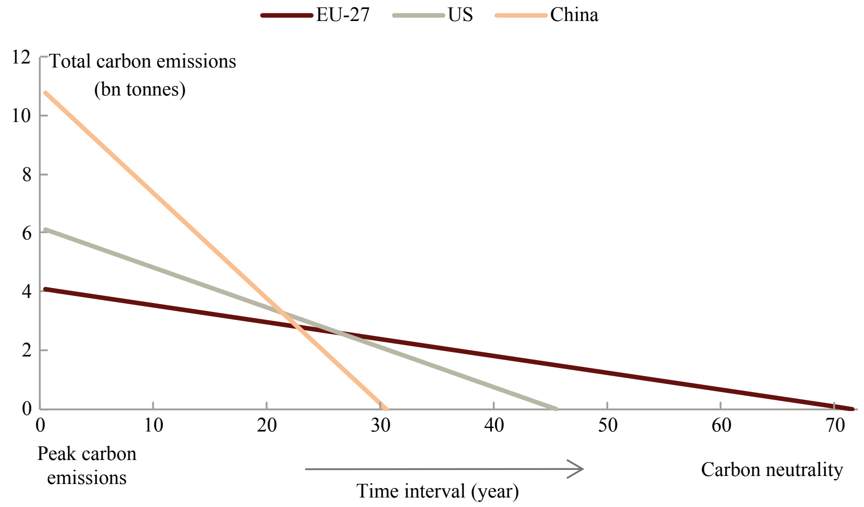


Fig. 1.2 Countries' estimated slope of emission reduction after the peak.[9] *Source* Our World in Data, World Bank, CICC Research. *Note* tonne = 0 represents the time when carbon peak is reached

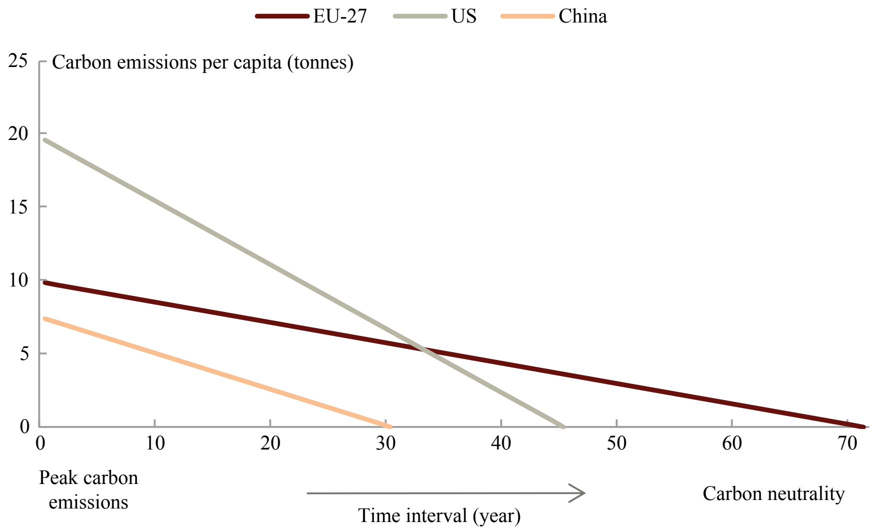


Fig. 1.3 Countries' estimated slope of per capita emission reduction after the peak.[10] *Source* Our World in Data, World Bank, CICC Research

[9] Since the Our World in Data database does not specify whether a country's carbon emissions are net emissions or gross emissions, there is a certain degree of uncertainty in the comparison here.

[10] Since the Our World in Data database does not specify whether a country's carbon emissions are net emissions or gross emissions, there is a certain degree of uncertainty in the comparison here.

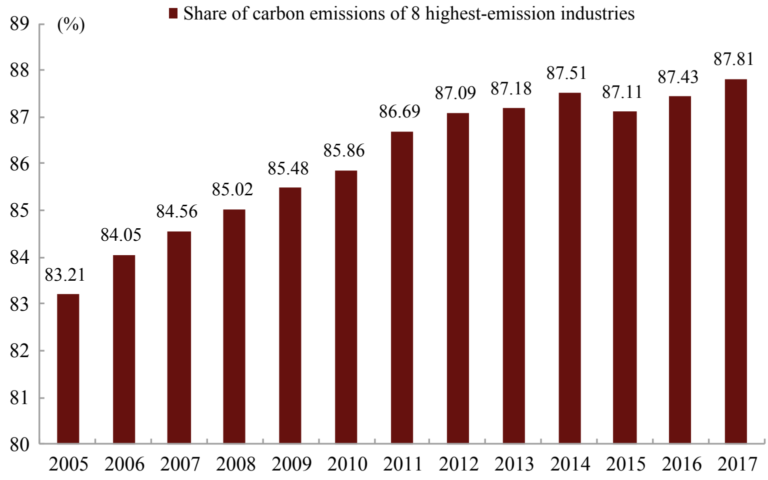


Fig. 1.4 Carbon emission proportion of 8 high-emission industries combined. *Source* CEADs, CICC Research

fundamental solution is to use zero-emission energy and zero-emission production technologies on the supply side. The supply side holds the key to China's goals to achieve peak emissions at 10.8bn tonnes and become carbon neutral in 30 years.

The key to exploring how to achieve carbon neutrality on the supply side lies in proper handling of emissions of 8 high-emission industries. In the Notice on Key Points for the Launch of the National Carbon Emissions Trading Market issued in 2016, the National Development and Reform Commission listed the petrochemicals, chemicals, building materials, steel, nonferrous metals, paper, power (thermal power), and airlines as high-emission industries. According to the CEADs, national carbon dioxide emissions increased from 3.003bn tonnes in 2000 to 9.339bn tonnes in 2017, and the proportion of these 8 industries[11] in total emissions increased from 80% to 88% (see Fig. 1.4), mainly driven by the power and steel industries. Among the 8 industries (see Fig. 1.5), the power industry accounted for the largest proportion of total emissions in 2017 (mainly thermal power, 44%), followed by steel (18%), building materials (13%), transportation (including airlines, 8%), chemicals (3%), petrochemicals (2%), nonferrous metals (1%), and paper (0.3%).

It should be noted that the CEADs' statistics on the industrial structure of carbon emissions are mainly based on the net emissions of the production process, and the indirect emissions generated by energy-intensive industries from their electricity consumption are not included in the emissions of the industries. The power industry accounts for nearly half of total emissions because the emissions from power consumption of all sectors are included in the power industry, while the emissions of other high-emission industries such as steel, building materials, nonferrous metals,

[11] For airlines, we use the carbon emission data of transportation (including airlines) due to the statistical scope of the CEADs.

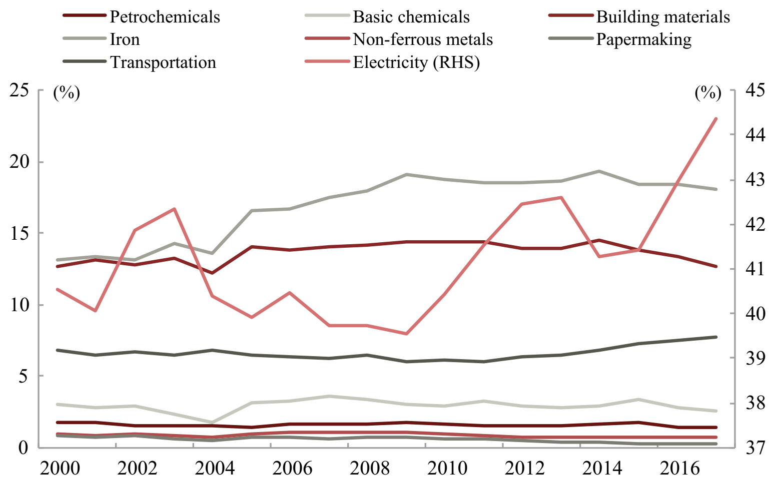


Fig. 1.5 Carbon emission proportions of 8 high-emission industries. *Source* CEADs, CICC Research

and chemicals are their direct emissions generated from the production process (such as the emissions generated from blast furnaces' consumption of iron ore and coke in steelmaking, and from decomposition of limestone and coal-fired kilns in the calcination of cement clinker).

Obviously, direct carbon emissions of the production process are highly related to the production technology, so we can also think about the road to carbon peak and neutrality from the perspective of improving production technology. For example, we can shift from coal power to solar power with zero emissions, and greatly reduce the emissions from steelmaking by using electric arc furnaces. For the emissions from cement clinker calcination that cannot be reduced by changing production technology, we can add carbon capture and storage facilities to reduce emissions or even achieve zero emissions. This idea is reflected as the "green premium". In this report, we define the green premium, which was coined by Bill Gates, as the percentage increase in the production cost of zero-emission technology vs. current emission-generating technology. In a sense, the key to carbon neutrality lies in reducing the green premium. When the green premium drops to zero, it means that carbon-neutral production technology is very mature and there is no need to use fossil energy.

However, the green premium varies greatly among different industries—the difference between building materials with the highest green premium and nonferrous metals with the lowest green premium is nearly 38 times. What can explain this difference? We divide the 8 high-emission industries into three sectors: power, transportation, and manufacturing (building materials, chemicals, steel, paper, petrochemicals, and nonferrous metals). With different production methods, these three sectors need to be discussed separately. The detailed analysis is as follows.

1. Power sector. The green premium in power generation is already negative. Currently hydropower and wind power generation costs are lower than thermal power, and nuclear power and solar power generation costs are slightly higher than thermal power. Based on the current power structure (thermal power 66%, hydropower 19%, wind power 6%, nuclear power 5%, and solar power 4%), the overall clean energy power generation cost is already lower than thermal power. However, the cost for the power grid to realize carbon neutrality is relatively high. Overall, our sector analysts estimate the green premium in the power sector in 2021 at 17%. For the power grid to absorb alternative energy, it is necessary to increase the flexibility of grid resource dispatch in the auxiliary service market, including power adjustment of thermal power units, pumping of pumped storage units, and charging of energy storage power stations. The cost for the power grid increases along with the proportions of wind power and solar power. Currently, thermal power peak shaving is still the lowest-cost method of grid dispatch. Before new technology emerges to greatly reduce the cost for the power grid to absorb alternative energy, thermal power is unlikely to be removed from the power system.
2. Transportation sector. The transportation sector includes roads, railways, airlines, and marine transport, which have quite different green premiums. Our sector analysts estimate the green premium in the transportation sector in 2021 at 68%. Under existing technologies, various transportation sub-sectors need to adopt different methods in order to achieve zero emissions. Assuming that passenger vehicles, medium/light-duty trucks and railways use clean power and heavy-duty trucks, airlines and marine transport use hydrogen energy, our sector analysts estimate the green premium at 18% in road passenger transport, 127% in road freight transport, 343% for airlines, 319% in marine transport, and –29% for railways. Since the cost of hydrogen energy is much higher than that of clean power, heavy-duty trucks, airlines, and marine transport have much higher green premiums than road passenger transport and light-duty trucks. As railways become increasingly electrified, their green premium has been negative.
3. Manufacturing sector. Under existing technologies, the green premium in the manufacturing sector is related to production technology. High-emission industries such as cement and chemicals need to adopt high-cost carbon capture and other technologies in order to achieve zero emissions. Our sector analysts estimate the green premium in 2021 at 138% in the building materials industry, 53% in the chemical industry, 15% in the steel industry, 11% in the paper industry, 7% in the petrochemical industry, and 4% in the nonferrous metals industry.

The analysis of these three sectors shows that the degree of technology maturity is an important determinant of the green premium. Taking the power sector with the highest emission proportion as an example, zero-carbon electricity has become feasible, as non-fossil energy technologies have made progress and wind and solar power costs have declined significantly in the past 10 years thanks to economies of scale, material replacement and efficiency improvement. Even taking into account grid costs, we expect electricity to achieve a negative green premium within 10 years.

In fact, the technological progress achieved by the power sector has made the largest contribution to the continuous decline of the CICC Green Premium Index over the past few years.

Manufacturing industries such as building materials, steel, nonferrous metals, and chemicals have relatively high green premiums. In addition to the cost increase resulting from electrification of the production process, the main reason is that the inevitable use of raw materials and burning of fossil energy in the production of some products makes it necessary to use hydrogen energy and carbon capture technologies in order to achieve carbon neutrality, but these technologies are not yet mature and have high costs. The transportation sector has a high green premium because heavy-duty trucks, airlines and marine transport need to replace existing fuels with hydrogen energy in order to achieve zero emissions, and a future decline in the green premium requires maturity of hydrogen energy technology.

In summary, technological progress plays an important role in lowering the green premium, but it is not the complete answer. We can see from the calculation method that the reduction in green premium can be achieved by relying on technological advancement to reduce the production cost of zero-emission technologies, or by increasing the production cost of emission-generating technologies. In fact, the latter is the most recommended way to achieve carbon neutrality under the framework of mainstream economics. According to mainstream economics, carbon emissions have become a problem because of their negative externalities. From a temporal perspective, it may take decades or even centuries for carbon emissions to have serious consequences by causing climate change, so this externality may have a relatively limited impact on current economic activities and daily life. From a spatial perspective, as carbon emissions enter global atmospheric circulation, emissions in any region will have an impact on the global climate. Since the global ecosystem is the basis for human survival and development, the problem of carbon emissions may have consequences that we cannot afford if it is not properly resolved. The current mainstream belief is that it is necessary to internalize the great externality of carbon emissions in order to solve it. From the perspective of green premium, this is to increase the production cost of existing emission-generating technologies.

The green premium is a more compatible analytical framework for thinking about the road to carbon neutrality that offers two basic paths: (1) the mainstream carbon pricing approach, which internalizes the negative externality of emissions through carbon tax or carbon market pricing mechanisms to increase the production cost of emission-generating technologies; and (2) technological advancement that makes zero-emission technologies more economically mature to reduce their production costs. Which of these two ways is more effective? What do they mean for the output and structure of the economy? How can we achieve the goals of carbon peak by 2030 and carbon neutrality by 2060? We will try to answer these questions in the CGE model analysis in the next section.

1.3 Four Scenarios: General Equilibrium Analysis Under CGE Model

The computable general equilibrium (CGE) model is a quantitative simulation system based on general equilibrium theory, macroeconomic structure relations and national accounting data that describes the operation of the economic system in a panoramic manner. The model is usually used to study the long-term, deterministic behavior of the overall economy and its response to external shocks, and has become a standard tool for global economic and policy analysis. In the model, changes in any part of the structure will have an impact on the entire system, leading to changes in the prices and quantities of goods and factors. When an exogenous shock occurs, the system will transition from one equilibrium state to another, thus fully demonstrating the impact of the shock.

Under constrained conditions, producers minimize costs while consumers maximize utility. The markets for factors of production and goods reach supply and demand balance through production, distribution, exchange, and consumption, thereby forming the equilibrium price. On the basis of the traditional CGE method for studying the environmental economy, we have incorporated endogenous climate-friendly technologies into the framework. Thus, the CGE model in this report comprises a production module, energy module, income and expenditure module, trade module, carbon tax/carbon trading module, dynamic module, climate-friendly technology module, and macro closure module.

In the context of carbon neutrality, the energy module is the key part of the model. The energy module consists of two parts: fossil energy (coal, oil, natural gas) and electricity. Thermal power and renewable energy make up the electricity system. On this basis, the energy structure is generated endogenously by the model and changes over time. Energy and non-energy factors are intermediate inputs, which together with the added value of capital and labor constitute total input. Essentially, we take fossil energy as a factor of production in the model and assign a price to it through carbon tax/carbon trading to correct the externality of carbon emissions. In this sense, the model has a similar core as the classical growth model of Nobel Prize laureate William Nordhaus, which includes carbon cycle. In the absence of climate-friendly technological advancements, companies will make a trade-off between the benefits of using one more unit of fossil energy and the additional costs paid given the carbon costs. The economy will eventually converge to a new equilibrium growth path, which often corresponds to lower economic output. The gap between the old and new equilibrium output can be understood as the social cost of emission reduction. Introduction of climate-friendly technologies can help reduce the social cost of emission reduction, thereby lifting the equilibrium growth path. Climate-friendly technologies are driven by investment, which is composed of corporate investment and carbon fee (from carbon tax or carbon trading) reutilization. More investment in climate-friendly technologies can help companies reduce the additional carbon cost to a greater extent, minimizing the negative impact of carbon tax/carbon trading on output.

1.3.1 Model Data

We choose 2017 as the base year. The main data sources of the model include the following: (1) China's social accounting matrix (SAM). According to China's 2017 input-output tables of 149 sectors, we obtain the energy input-output tables of 29 sectors, including coal, oil, natural gas, thermal power, and renewable energy through merge and split. The fiscal and tax data in the SAM are derived from the 2018 China Taxation Yearbook and 2018 Finance Yearbook of China. (2) Exogenous elasticity of substitution, such as the elasticity of substitution between inputs in the production function, the elasticity of substitution between imported and domestic products in the CES function of the foreign trade module, etc. The data makes reference to the Global Trade Analysis Project (GTAP) database. (3) Carbon dioxide emission coefficients derived from calculating sectors' carbon dioxide emissions and energy product consumption. The carbon dioxide data come from the CEADs.

1.3.2 Scenario Assumptions

In order to quantify the different effects of the aforementioned two paths in terms of carbon neutrality and economic development, we examine the following four scenarios:

1. Business-as-usual scenario (BAU): No constraint is imposed on carbon emissions. The economic growth rate refers to the forecast made by the CICC macro team based on the proposal to double China's economic aggregate or per capita income by 2035.
2. Carbon tax scenario (M1): A unified carbon tax is imposed on carbon-emission industries so that China can strive to achieve the goals of carbon peaking by 2030 and neutrality by 2060, and keep peak emissions as close to 10.8bn tonnes as possible.
3. Carbon trading scenario (M2): Carbon trading is introduced for 8 high-emission industries. Free carbon allowances are set based on the green premium of industries—free allowances should be lower for industries with higher green premiums to strengthen their incentives to cut emissions. Thus, China can strive to achieve the goals of carbon peaking by 2030 and neutrality by 2060, and keep peak emissions as close to 10.8bn tonnes as possible.
4. Carbon tax + carbon trading + technological progress scenario (M3): A three-pronged approach is adopted to achieve the goals of carbon peaking (at 10.8bn tonnes) by 2030 and neutrality by 2060, while maintaining economic growth.

1.3.3 BAU Scenario

In this scenario, there is no constraint on carbon emissions and the only goal is to double China's economic aggregate or per capita income by 2035. The figures below depict the corresponding economic growth and carbon emission trajectory simulations: GDP will grow at an average annual rate of 5.2% from 2021 to 2030[12]; carbon emissions will be 15.8bn tonnes in 2030, and after deducting 900mn tonnes of carbon sequestration, net emissions will be 14.9bn tonnes.

1.3.4 Carbon Tax Scenario (M1)

In theory, as long as China keeps raising carbon tax, the country can achieve the goals of carbon peaking by 2030 and neutrality by 2060, and keep peak emissions close to 10.8bn tonnes. However, a relentless increase in carbon tax could paralyze the economic system—in that case, the CGE model is unable to converge to an equilibrium path. This means that the setting of carbon tax needs to take into account both economic development and carbon neutrality goals. Based on the green premium calculated by our sector analysts, we derive the parity carbon cost[13] of the whole society at about Rmb377/tonne. Countries that have levied a carbon tax (mostly developed countries) set the tax at Rmb80-800/tonne. Our basic materials analysts estimate that for industries to remain profitable, the maximum affordable carbon tax is Rmb100/tonne for steel and cement industries and Rmb60/tonne for the aluminum industry. Meanwhile, our calculations show that the CGE model cannot converge to an equilibrium path when carbon tax is higher than Rmb150/tonne.[14] After considering all these factors, we set carbon tax at Rmb100/tonne. Later we will conduct a sensitivity analysis of carbon tax in a bid to identify what would be an extreme level of carbon tax and the time path of carbon tax rate change.

In this scenario, carbon emissions continue to increase and cannot be peaked, let alone achievement of carbon neutrality. Specifically, net emissions will reach 12.3bn tonnes in 2030[15] and 33.4bn tonnes in 2060 (see Fig. 1.6), but still 2.6 and 16.6bn tonnes lower than the BAU scenario. GDP will decline by 0.6% in 2030 and 0.9% in 2060 compared to the BAU scenario. Prices are under greater upward pressure than in the BAU scenario, especially in the first few years. Wholesale & retail, restaurant & hotel, transportation, and information & financial service industries

[12] Excluding 2021 with high growth, the average annual growth rate will be 4.8%.

[13] This refers to the extra cost that emitters need to pay for carbon emissions, calculated based on the green premium, to ensure that the production cost of emitters is on par with the production cost under carbon–neutral technology.

[14] Here we assume that carbon tax is constant. If carbon tax increases year by year, it can exceed the Rmb150/tonne limit.

[15] Regarding carbon sequestration, we refer to the calculations made by the Institute of Climate Change and Sustainable Development of Tsinghua University and CICC sector analysts.

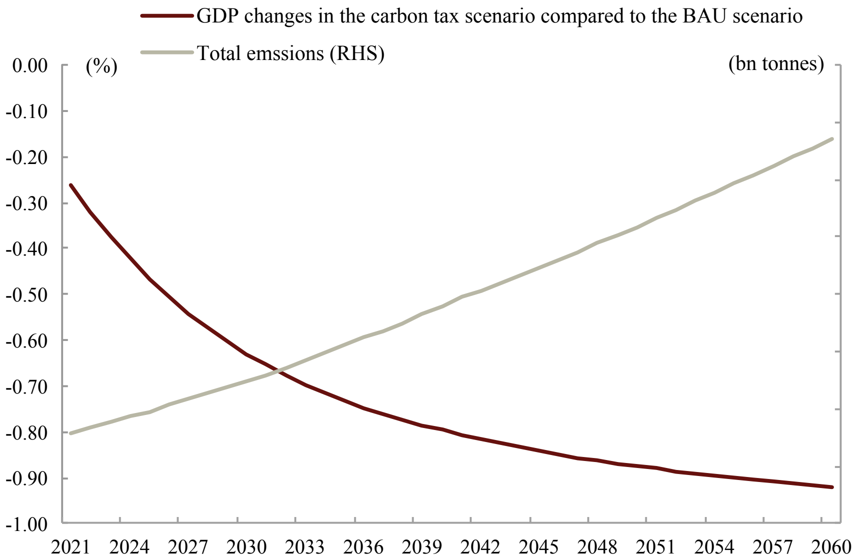


Fig. 1.6 GDP loss in the carbon tax scenario compared to the BAU scenario. *Source* CEADs, Centre for Economic Systems Simulation Research, CICC Research

will face higher price pressures in the next few years (see Fig. 1.7). The imposition of a carbon tax will also bring about changes in the economic structure. The output of the power sector excluding thermal power in 2030 will be more than 2% higher than in the BAU scenario, while the output of coal, thermal power, natural gas extraction, and building materials industries will be under pressure (the output of coal processing and mining industries will be over 7% lower than in the BAU scenario).

1.3.5 Carbon Trading Scenario (M2)

We assume that only the petrochemical, chemical, building materials, steel, nonferrous metals, paper, power, and airline industries will be engaged in carbon trading in the unified carbon market, and we determine the free emission allowance for each industry based on the green premium calculated by our sector analysts and Guangdong province's 2020 Carbon Emission Allowance Allocation Implementation Plan. Free allowances should be lower for industries with higher green premiums to increase their incentives to switch to zero-emission technologies. The nonferrous metals, petrochemical, and paper industries with lower green premiums have a free allowance of 90%; the steel, power, chemical, and airline industries have a

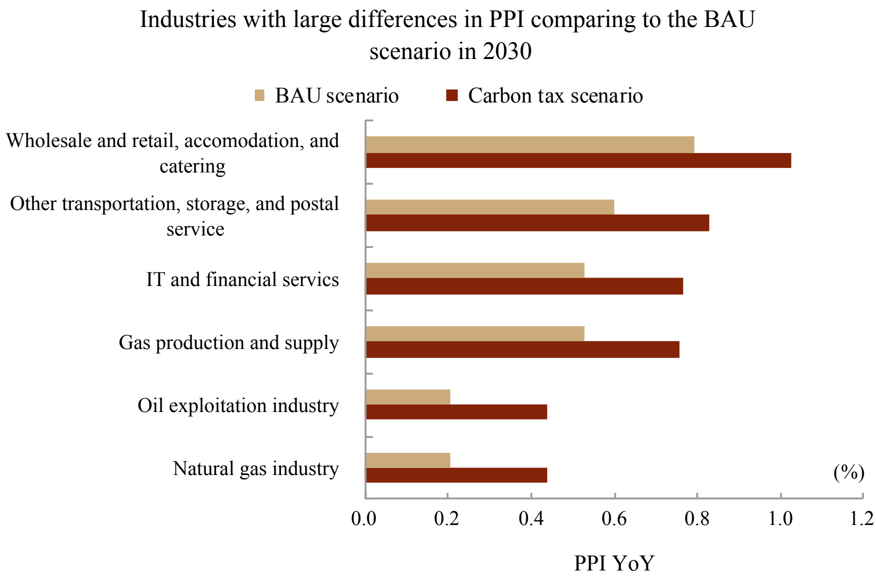


Fig. 1.7 Industries with higher cost pressures in the carbon tax scenario. *Source* CEADs, Centre for Economic Systems Simulation Research, CICC Research

free allowance of 80%; and the building materials industry with the highest green premium has a free allowance of 70%.[16]

In this scenario, carbon emissions would peak in 2042 at 17.1bn tonnes, before declining to 13bn tonnes in 2060 (see Fig. 1.8). Although this scenario still does not result in carbon neutrality, it represents a considerable improvement compared to the carbon tax scenario. GDP performance in this scenario is also better than the carbon tax scenario. Compared to the BAU scenario, GDP would only decrease by an average of 0.15% per year in the next few decades. Similar to carbon tax, carbon trading would also bring inflationary pressure, especially in the first few years. The thermal power, building materials, chemical, steel, and airline industries would face greater price pressures (Fig. 1.9). In terms of industry structure, the proportion of the power sector excluding thermal power in 2030 would be much higher than in the BAU scenario, while of coal processing and mining industries would be 10% and 5.5% lower than in the BAU scenario.

In the computable general equilibrium model, factor prices are jointly determined by the forces of supply and demand in the market, and carbon trading prices are no exception. The parity carbon cost implied by the green premium measures the relative cost of emission-generating technology to zero-emission technology. When the carbon trading price is close to this cost, theoretically effective emission reduction

---

[16] Here we only analyze the allowance issue from the perspective of economic model simulation. In practice, CICC sector analysts' calculation shows that a 70% free allowance may be too low for the cement industry.

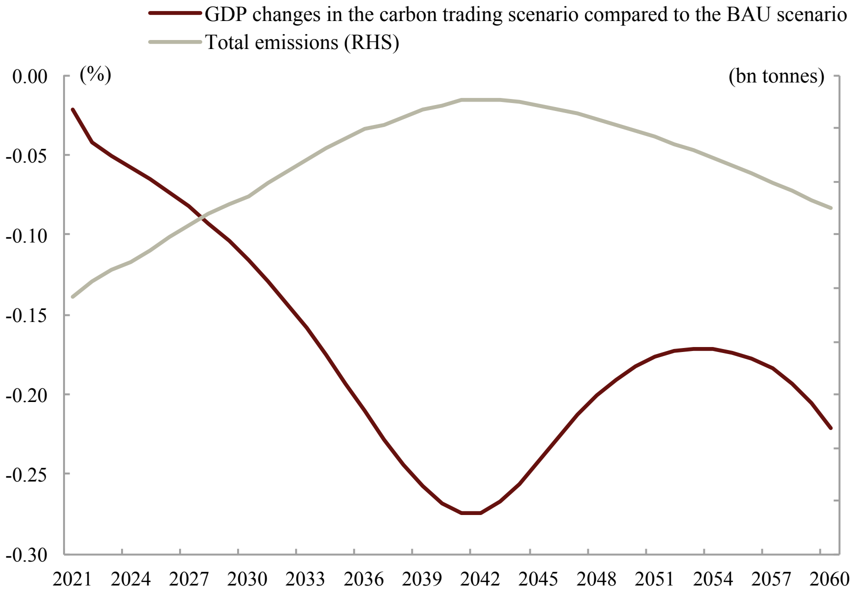


Fig. 1.8 GDP loss in the carbon trading scenario compared to the BAU scenario. *Source* CEADs, Centre for Economic Systems Simulation Research, CICC Research

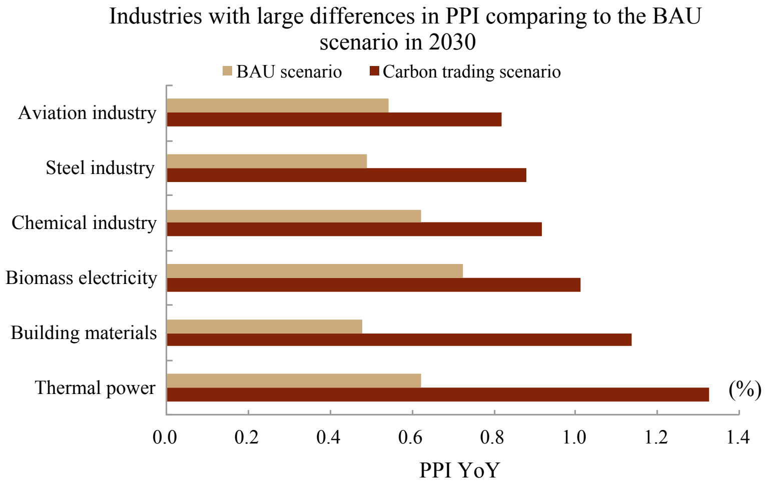


Fig. 1.9 Industries with higher cost pressures in the carbon trading scenario. *Source* CEADs, Centre for Economic Systems Simulation Research, CICC Research

can be achieved. According to the analysis in the M2 scenario, assuming that a carbon trading mechanism is introduced in 2021, the carbon price would rise from Rmb31/tonne at first to Rmb650/tonne in 2060. As mentioned above, the overall parity carbon cost implied by the green premium is Rmb377/tonne. Simulation results show that the carbon trading price in the next 20 years will be much lower than the parity carbon cost, which may be an important reason why emissions cannot be peaked in time. When the carbon price approaches or even exceeds the parity carbon cost, emissions are significantly reduced. This means that raising the carbon price, especially when it is raised to near the parity carbon cost, can effectively reduce emissions.

1.3.6 Carbon Tax + Carbon Trading + Technological Progress Scenario (M3)

As mentioned above, while carbon pricing (in the form of a carbon tax or a carbon market) is the mainstream way to solve the externality of emissions, carbon pricing alone cannot achieve a balance between GDP growth and carbon neutrality. In other words, if the GDP growth target is not abandoned, it will be difficult to achieve carbon neutrality through carbon pricing alone. Therefore, we need to shift from the mainstream path of carbon pricing to the green premium analysis framework. It is necessary to not only increase the production cost of emission-generating technologies through carbon pricing, but also reduce the production cost of zero-emission technologies through technological progress.

For the analysis of technological progress, we adopt the "S-curve" theory of technological innovation. Freeman and Louçã (2001) proposed a long wave (or Kondratieff Wave) theory of technological revolution from a historical perspective. The life cycle of any widely used technology consists of six phases: (1) the laboratory/invention phase, (2) decisive demonstration, (3) explosive growth, (4) continued high growth, (5) slowdown, and (6) maturity. The whole process forms an "S-shaped curve", which may be driven by the investment path, according to Köhler (2005). This S-shaped curve is widely accepted as a way to describe technological change. In our model, this S-shaped curve in a reduced form encompasses all climate-friendly technologies: energy efficiency technologies, emission reduction technologies, carbon sequestration, carbon capture and storage, etc.

Take the power industry that accounts for the bulk of carbon emissions as an example. Using clean energy (such as solar energy) for power generation on the supply side and increasing the electrification rate on the demand side is the best technological path to achieve carbon neutrality. Solar power generation technology is mature and has been successfully commercialized. On the other hand, grid absorption still faces challenges given that energy storage has not yet reached parity. For power transmission, it is necessary to establish distributed smart grids and change the power structure. Breakthroughs must be made in infrastructure technologies that

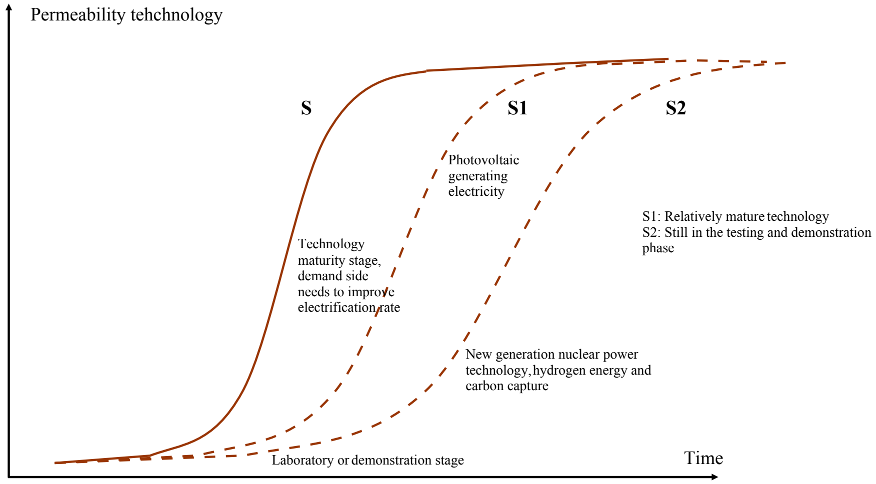


Fig. 1.10 Climate-friendly technology advancement curve. *Source* Centre for Economic Systems Simulation Research, CICC Research

enable the transition from a centralized grid to a smart grid and the realization of full electrification. On the application side, the fundamental solution is to comprehensively increase the electrification rate (electric vehicles, electric arc furnaces for steelmaking, etc.). In Fig. 1.10, the vertical axis represents the extent of application or penetration rate of technology over time, and the S1 curve depicts the technology path of the power industry towards carbon neutrality. We are now at a stage where the technology curve gradually begins to steepen.

Compared to the technology path represented by the S1 curve, the S2 curve represents a new generation of nuclear power technology, hydrogen energy technology, and carbon capture technology. These technologies are still in the laboratory or demonstration phase and are far from successful commercialization, meaning great uncertainty. We combine the S1 and S2 curves to derive the S curve, which represents all climate-friendly technologies. We define it as a share of non-carbon technology (SNCT) curve. The faster the curve begins to steepen, the faster the technology is commercialized; the steeper the curve is, the faster the large-scale application of the technology will be.

The SNCT curve measures the extent of decline in the carbon emission coefficient of the economic system with the advancement of climate-friendly technologies. Here, we use a curve to simulate the entire life cycle of climate-friendly technologies. This curve is determined by five exogenous parameters (to construct the curve shape and simulate technology life cycle, growth rate, etc.) plus an endogenous variable (climate-friendly technology investment). We assume that taking actions to address climate change will lead to a transfer of investment from traditional energy technologies to climate-friendly technologies, and this can effectively increase the share of climate-friendly technologies. In this sense, this curve in a reduced form summarizes a series of investment-driven technological advancements from improving energy efficiency to decarbonizing and reducing carbon (such as carbon capture and carbon fixation). Therefore, this curve explains how to lower the carbon emission coefficient and thus reduce emissions.

In this scenario, we adopt the same carbon tax of Rmb100/tonne as in the M1 scenario and the same carbon allowances for the 8 high-emission industries as in the M2 scenario. Through simulation, we found that the combination of carbon tax, carbon trading, and technological progress can achieve the dual goals of economic growth and carbon neutrality. The GDP loss compared to the BAU scenario is almost negligible. After 2040, GDP even exceeds that in the BAU scenario, indicating that technological progress offsets or even more than offsets the negative impact of carbon pricing on economic growth. In this scenario, carbon emissions peak in 2030 at 10.9bn tonnes, before decreasing year by year towards the goal of net zero emissions (see Fig. 1.11).

The simulation results also show that carbon tax and carbon trading still put upward pressure on costs in the economy in the early stages, possibly because the effect of technological progress has not fully kicked in. However, the cost pressure is milder than in the scenarios without technological progress (see Fig. 1.12 for industries with higher cost pressures in the M3 scenario). We analyze changes in the industrial structure from two perspectives: (1) the change in industry output compared to the BAU scenario, and (2) the change in the proportion of industry output over time. First, the output of the solar power, hydropower, wind power, and nuclear power industries in 2030 all increase more than 3% compared to the

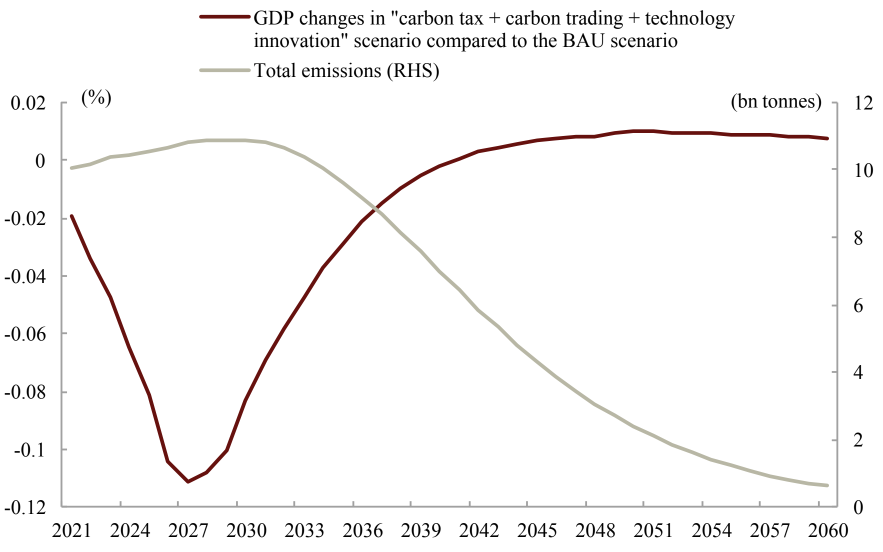


Fig. 1.11 GDP in the M3 scenario compared to the BAU scenario. *Source* CEADs, Centre for Economic Systems Simulation Research, CICC Research

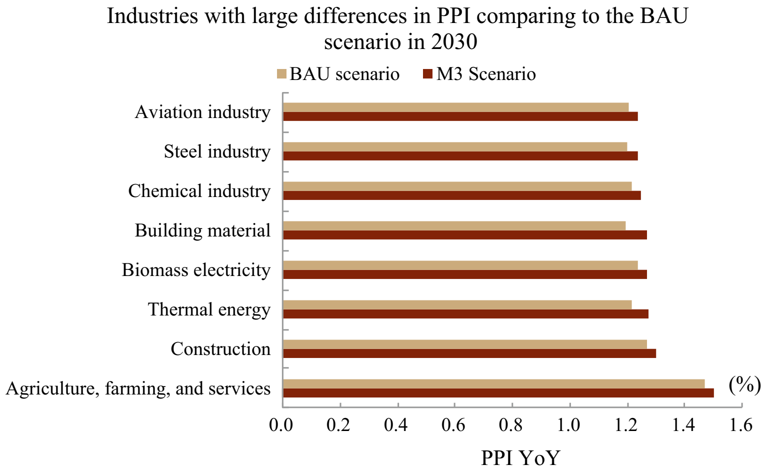


Fig. 1.12 Industries with higher cost pressures in the M3 scenario. *Source* CEADs, Centre for Economic Systems Simulation Research, CICC Research

BAU scenario, while the output of coal processing and mining industries shrink considerably. Second, the proportions of output of agriculture, public services, and light industries show more obvious declines over time, while the proportions of output of equipment manufacturing, real estate & leasing, and information & financial services industries increase year by year.

The carbon trading price will rise gradually from Rmb10/tonne in 2021 to Rmb140/tonne before 2030. At a time when climate-friendly technologies have not been adopted on a large scale, rising carbon prices will help peak emissions in a timely manner and at around 10.9bn tonnes. When green technologies are widely used, carbon prices will drop. As an endogenous variable of the S-shaped technology curve, investment is the key to driving technological progress. The model estimates that R&D investment in green technologies will account for about 2% of GDP, and it will increase gradually in the first few years to help bring technologies from the laboratory phase into commercial use. In the M3 scenario, the climate-friendly technology curve SNCT simulates the shape of the S curve. The SNCT will reach 0.32 in 2030 and 0.99 in 2060, meaning that the carbon emission coefficient[17] in 2030 and 2060 will be 68% and 1% respectively of that in 2020 (see Fig. 1.13). As such, China will be able to strike a balance between the existing economic growth objective and the new carbon neutrality goal. The energy structure will also be optimized gradually, with clean energy accounting for 44% in 2030 and 96% in 2060.

[17] Carbon emissions per unit of output.

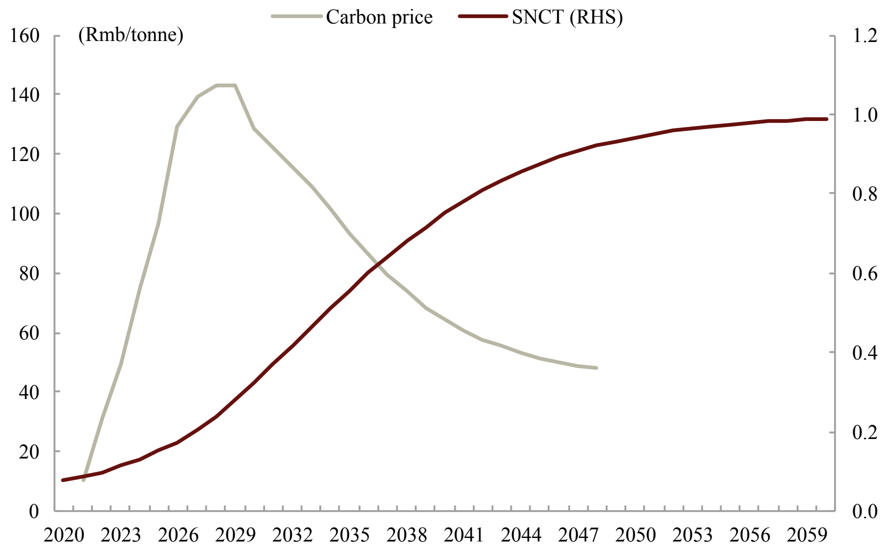


Fig. 1.13 Carbon trading price and Climate-friendly technology advancement curve in the M3 scenario. *Source* CEADs, Centre for Economic Systems Simulation Research, CICC Research

1.3.7 Sensitivity Analysis of Technology Curve

A comparative analysis of the above-mentioned four scenarios shows that technological progress is essential to balance economic growth and carbon neutrality goals. However, since technological innovation is highly uncertain, we need to examine the impact of an optimistic/pessimistic scenarios for technology on GDP and carbon emissions. We assume that the climate-friendly technology curve in the M3 scenario is the baseline scenario of technological progress, and the pessimistic scenario is a situation in which technological development is disappointing or commercialization is difficult. Intuitively, the technology curve in the pessimistic scenario should be flatter than in the baseline scenario: the laboratory phase may be longer, large-scale application of technology may face greater resistance, or the penetration rate of technology may be lower. In reality, the pessimistic scenario may correspond to technologies that are not yet mature and quite uncertain, such as hydrogen energy and carbon capture. The opposite is true for the optimistic scenario.

Consistent with intuition, GDP is considerably affected in the pessimistic technological scenario (Fig. 1.14), and the carbon emission curve is significantly elevated—emissions do not peak until 2034 and the peak is as high as 13.4bn tonnes (Fig. 1.15). The simulated technology curve is also in line with our thinking about the technology path in the pessimistic scenario. Due to disappointing technological progress, the share of clean energy is relatively low and the carbon trading price is much higher after carbon emission peaks. In addition, compared with baseline and optimistic

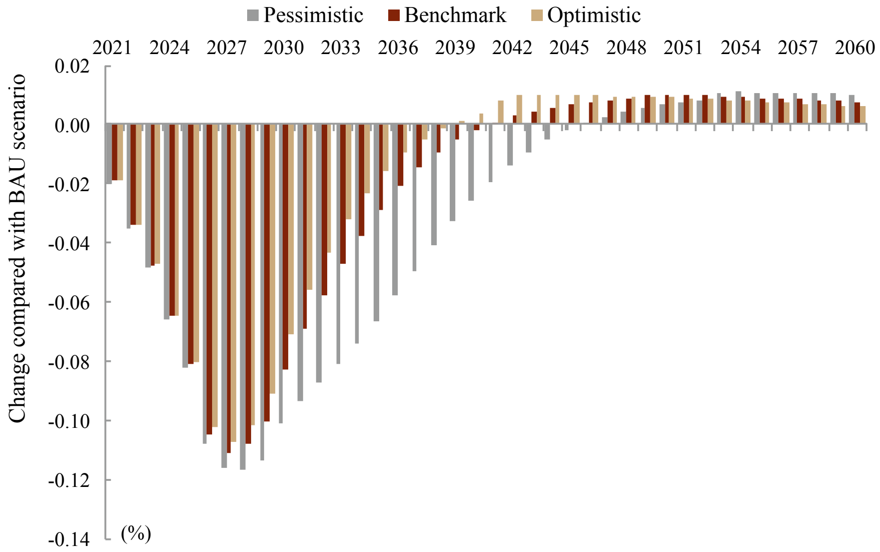


Fig. 1.14 GDP changes in different technological scenarios compared to the BAU scenario. *Source* CEADs, Centre for Economic Systems Simulation Research, CICC Research

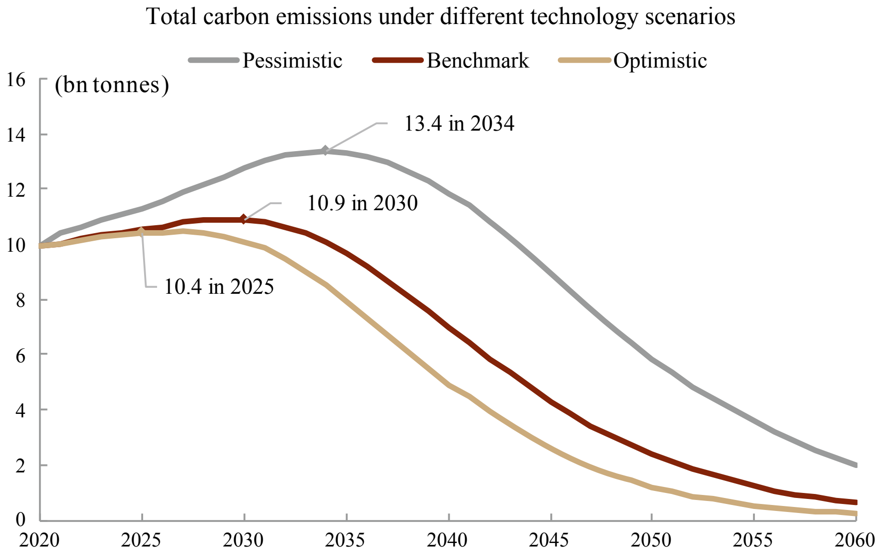


Fig. 1.15 Carbon emission simulation. *Source* CEADs, Centre for Economic Systems Simulation Research, CICC Research

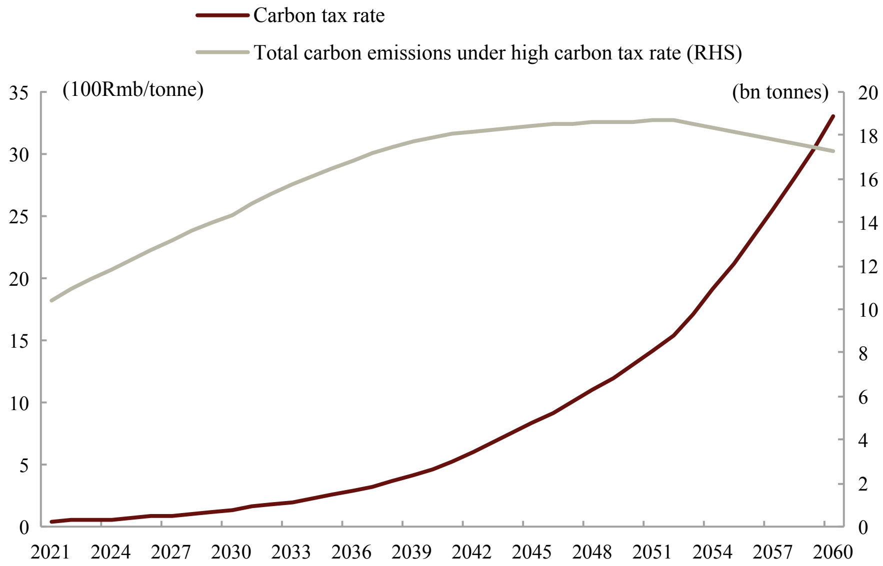


Fig. 1.16 Extreme carbon tax rate and carbon emission simulation. *Source* CEADs, Centre for Economic Systems Simulation Research, CICC Research

scenarios, the carbon trading market lasts longer in the pessimistic scenario—the price mechanism needs to play a greater role in both price and time dimensions.

1.3.8 Sensitivity Analysis of Carbon Tax

According to the simulation of the M1 scenario, it is difficult to peak carbon emissions at a carbon tax that can achieve model convergence. As mentioned earlier, as long as the carbon tax rate is high enough (regardless of economic growth), it can correct the negative externality of carbon emissions and turn the emission curve down at a certain point. In the M1 scenario, emissions fail to peak before 2060, illustrating two points: (1) the calculation time span is not long enough; or (2) the carbon tax rate used in the model is too low. Here, we set a goal of peaking carbon emissions by 2060[18] and calculate how much carbon tax is required. After simulation calculations, we derive a carbon price index (see Fig. 1.16). This curve roughly follows an exponential increase, from Rmb46/tonne in 2021 to Rmb140/tonne in 2030, and then to Rmb3,300/tonne in 2060. With such a high carbon tax, emissions would enter a plateau phase in 2040 and begin to slowly decline in 2052. Economic growth is also under great pressure, with a GDP loss of 3%–5% in the final 10 years compared to the BAU scenario (Fig. 1.17). This simulation further confirms that carbon tax alone

[18] With only a carbon tax, neutrality is impossible, so we only see if the peak can be reached.

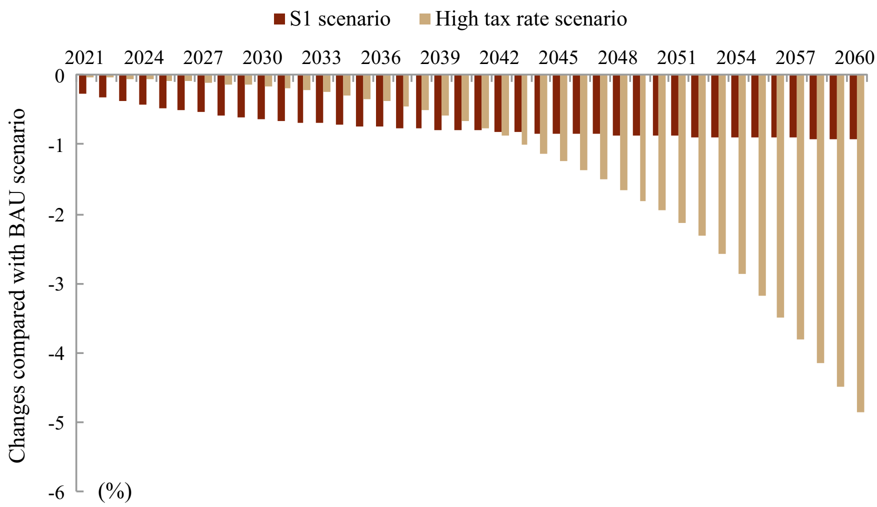


Fig. 1.17 GDP change compared to the BAU scenario. *Source* CEADs, Centre for Economic Systems Simulation Research, CICC Research

cannot enable China to achieve the goals of carbon peak by 2030 and neutrality by 2060.

1.4 Road to Carbon Neutrality = Technology + Carbon Pricing + Social Governance

The aforementioned general equilibrium analysis based on the CGE model shows that internalization of the negative externality of carbon emissions alone could not solve the conflict between economic growth and carbon neutrality goals, and only a combination of technology and carbon pricing under the green premium framework could help strike a balance between the two goals. Reaching such a conclusion does not mean the end of the research in achieving carbon neutrality. Instead, it marks the starting point of exploring China's road to carbon neutrality. For example, given that technology is so important to achieve carbon neutrality, what carbon neutral technologies are worth nurturing? What is the current development status of these technologies? We will discuss carbon neutral technologies in more detail in the following chapters.

In terms of carbon pricing, the establishment of a unified national carbon market is accelerating, and the 8 high-emission industries may gradually be included in the unified carbon market during the 14th FYP period. As China promotes carbon neutrality, the implementation of a unified carbon price for different industries through the establishment of a unified market seems to have become a consensus in the country. However, our analysis shows that the situation may not be that simple.

For example, when internalizing the negative externality of emissions, it may not be appropriate to calculate the discounting of social costs according to mainstream practices, and a differentiated pricing perspective based on net social costs should be adopted instead; the analysis of green premium shows that it may not be appropriate to choose a carbon pricing method based solely on the proportion of emissions; also, a unified carbon market may exacerbate pollution problems in the Beijing-Tianjin-Hebei region. For detailed analysis on these issues, please refer to a later chapter that directly addresses carbon market, carbon tax and other carbon pricing methods.

More importantly, technology and carbon pricing are just two basic means to reducing the green premium, and they could not represent a comprehensive solution to carbon neutrality under this framework. According to the calculation of our sector analysts, the green premium of the power industry will be −3.9% in 2030. A negative green premium means that in terms of economic performance, zero-emission technologies would be decisively superior to emission-generating technologies. However, due to the path dependence of economic development, or a lack of sufficient awareness of the importance of carbon neutrality among decision makers or the general public, industries may not shift to more economical zero-emission production technologies, and may instead stick with high-cost emission-generating technologies. Such problems cannot be resolved by relying solely on "technology + carbon pricing". It also requires the intervention of social governance or public policy.

From the perspective of social governance, there are mainly three types of policies, i.e., price-based, command-based and publicity-based policies. In fact, technology, carbon pricing, and social governance, which together constitute the road to carbon neutrality, are closely correlated with each other. For example, technological progress and improvement in production processes cannot be achieved without support from public policies such as fiscal subsidies. Carbon tax and auctions in the carbon market are important sources of such funds. Carbon pricing itself is part of public policies, and publicity-based policies could help raise people's awareness of carbon neutrality, and thus reduce friction costs in the implementation of carbon pricing policies. In view of the green premium analysis framework, the "technology + carbon pricing + social governance" approach is important to the road to carbon neutrality in three ways.

First, the approach addresses issues related to innovation and fairness on the road to carbon neutrality. The green premium only measures the difference in production cost between zero-emission technologies and emission-generating technologies, while it does not measure the total cost borne by the society for carbon neutrality. The simulation calculations based on the CGE model show that the output of coal, building materials, and chemical industries may shrink considerably, while the proportions of output of information & financial services and real estate & leasing industries may expand. Such structural changes may cause a series of social problems. For example, the large-scale launch of zero-emission power generation capacity will inevitably lead to large-scale idling of thermal power assets, as well as subsequent layoffs at coal mines and thermal power plants, and an increase in non-performing loans at banks. Transformation will be required for coal-producing provinces. In a more general sense, the reliance on innovation to achieve carbon neutrality may lead to unfair development between high-carbon industries, workers and regions, and low-carbon industries, workers, and regions. Such problems may not be resolved by relying solely on the "technology + carbon pricing" approach, and coordinated arrangements and early planning from the perspective of social governance are needed. Whether the innovation- and fairness-related issues can be well addressed determines whether the entire society can continue to move towards carbon neutrality.

Second, the "technology + carbon pricing + social governance" approach is vital to coping with risks of rebound in the green premium. The large-scale adoption of zero-emission technologies may result in shrinking demand for emission-generating technologies. For example, the large-scale launch of clean energy power generation capacity will affect the demand for thermal power generation, thereby reducing fossil energy prices and production costs of emission-generating technologies. Such a phenomenon may lead to a rebound in green premiums. If the demand for fossil energy continues to shrink, the decline in prices will likely also lead to spontaneous supply-side contraction. Therefore, with large-scale promotion of zero-emission technologies, fossil energy prices may face both upward and downward pressures. It is difficult to predict which factor will dominate, but one thing is certain: the change in the green premium will be a dynamic process, and the green premium may rebound in the downward trend, which may even weaken the momentum around reaching carbon neutrality in society as a whole. Therefore, it is necessary to restrict the re-expansion of fossil energy-based power generation capacity through command-based policies when it is economically feasible to adopt zero-emission technologies on a large scale.

Third, "technology + carbon pricing + social governance" approach puts emphasis on the role of green finance. As we mentioned earlier, the estimated green premium of the power industry is negative in 2030. This means that even with carbon pricing and technological progress, the economically advantageous clean power generation technologies will not fully replace thermal power generation technologies in the next 10 years. This may be because technologies still need to be improved or carbon prices are not high enough. However, it also reveals a social governance problem, i.e., how to formulate reasonable public policies to promote the formation of economically beneficial zero-emission production capacity as soon as possible so as to accelerate the replacement of existing emission-generating assets. We believe green finance will play an important role in this regard. In fact, the significance of green finance to carbon neutrality lies not only in accelerating the promotion of mature technologies, but also in the highly uncertain R&D phase. For example, carbon neutral technologies that are still in the laboratory phase such as hydrogen energy and carbon capture still require a large amount of R&D funding. Do carbon neutral technologies require different forms of financial support in the two different stages of development? What are the implications of green finance for carbon neutrality? We will examine these topics in greater detail in Chapter 4.

The above thoughts are based on the assumption of a closed economy. As China emphasizes the new dual-circulation pattern with domestic and foreign markets reinforcing each other, it is also necessary to take an international perspective when dealing with carbon emissions, an externality that requires long-term and comprehensive efforts. On March 10, 2021, the European Parliament passed a resolution on the EU's Carbon Border Adjustment Mechanism (CBAM). According to the mechanism, if economies that have trade relations with the EU do not comply with the EU's carbon emission regulations, the EU can impose carbon tariffs on goods imported from them. This can be regarded as the first step towards the implementation of Nordhaus' international "Climate Club" proposal. It is also a direct application of the carbon tax-based pricing mechanism at the governance level of the international community. What are the implications of the "technology + carbon pricing + social governance" approach from an international perspective and how will it play its role? We will analyze these in the chapter that focuses on international cooperation.

Chapter 2
Balancing Efficiency and Fairness: Kaldor-Hicks Improvement?

Abstract This chapter mainly discusses two issues related to achieving carbon neutrality: innovation and fairness. We believe that innovation (efficiency enhancement) is critical to carbon neutrality, and the attendant fairness-related issues need to be addressed. To efficiently achieve carbon neutrality, we believe the following measures should be simultaneously taken: (1) internalizing external costs by raising carbon prices; (2) fundamentally altering the mode of production by expediting eco-innovation; and (3) improving the social governance system by encouraging low-carbon lifestyles, and reaching a consensus on environmental protection among the general public. Among these measures, we believe innovation is the key, as it can help reduce carbon emissions per unit of energy consumption as well as energy consumption per unit of GDP. In the long term, we believe innovation is also the major driving force for economic growth. In retrospect, we find that each technological revolution has led to a reshaping of the global economic landscape, and countries with an early start to innovation usually achieved economic advances in the end. Eco-innovation is a general-purpose technology innovation that has a greater effect in terms of improving productivity. Nevertheless, innovation does not happen overnight or without hindrances. Eco-innovation features double externality, and as a result sees slower progress and faces more barriers than general innovation. Public sector policies and capital investment (green finance) need to be coordinated, in our view, to inspire innovation among enterprises and to remove the systemic obstacles to innovation. Carbon neutrality may cause fairness issues both domestically and internationally. Globally, principles of fairness and each country's stage of development should be taken into consideration to avoid unfair distribution of rights, responsibilities and interests among different countries. Domestically, emission reduction may lead to fairness problems between different social classes, generations, sectors, and regions. Hence, fiscal policies should play a more important role in income distribution and cross-cycle adjustments to prevent worsening imbalances in residents' income distribution and regional development.

The COVID-19 pandemic that swept the world in 2020 shows that an unexpected crisis related to public health and climate issues is no longer a challenge that is far away from us. Such challenges will cause substantial economic losses and endanger

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_2

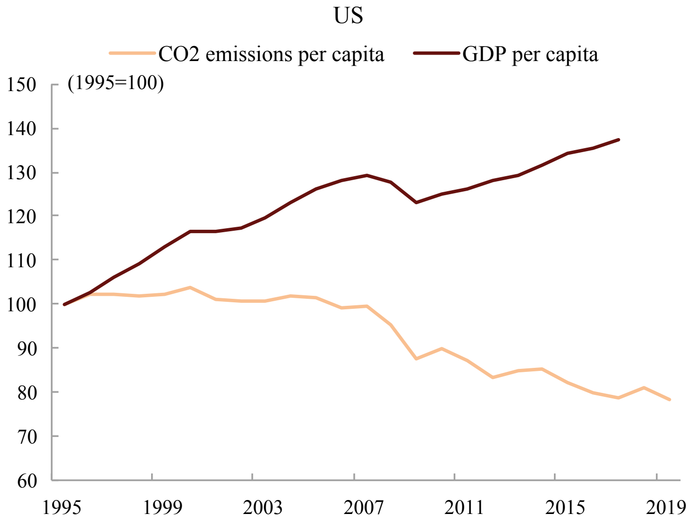


Fig. 2.1 GDP per capita and carbon emissions in the US. *Source* Our World in Data, CICC Research

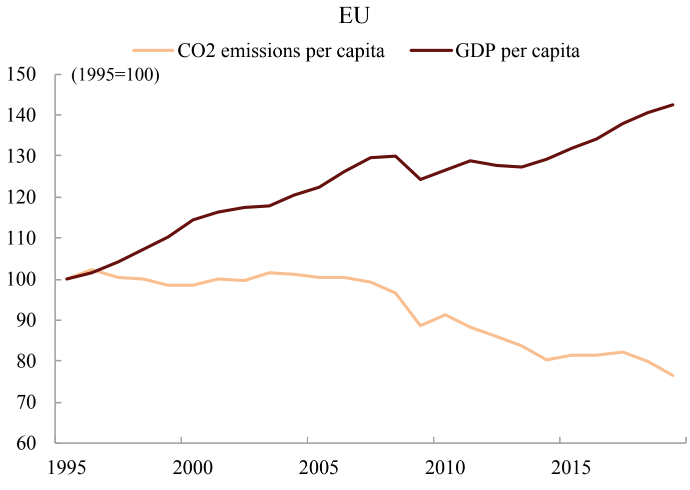


Fig. 2.2 GDP per capita and carbon emissions in the EU. *Source* Our World in Data, CICC Research

human life, health, and safety. In the past decade or so, carbon emissions in Europe and the US have shown a downward trend, while China's carbon emissions were still growing, which means that it is increasingly important for China to reduce carbon emissions (Figs. 2.1, 2.2 and 2.3).

How to achieve carbon neutrality? What effects will this process have on the economy? What challenges will we face? What are the policy implications? We will answer these questions in the following sections.

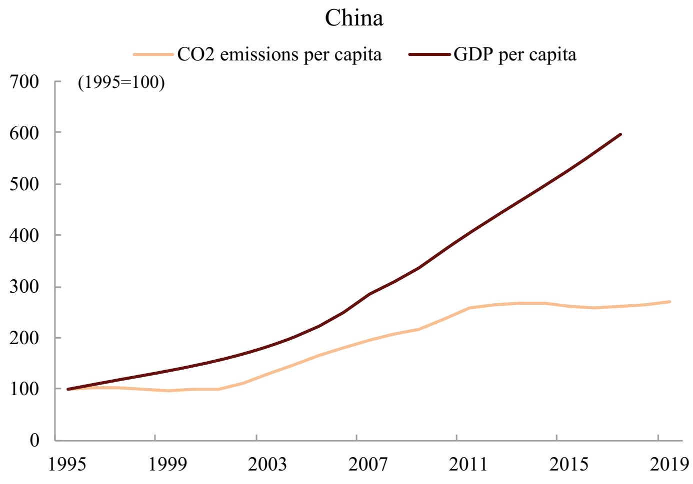


Fig. 2.3 GDP per capita and carbon emissions in China. *Source* Our World in Data, CICC Research

2.1 Three Approaches to Achieving Carbon Neutrality: Innovation is the Key

2.1.1 Carbon Neutrality Cannot Be Achieved Through "zero-sum game"

The first approach people most likely have in mind to achieve carbon neutrality is adjusting the structure of industries. For example, policy guidance can reduce the proportion of high-emission industries (usually high-energy-consuming manufacturing industries) in the economy and vigorously develop low-emission industries (usually service industries). This is also the experience of European countries and the US. However, historical experience suggests that high-emission industries usually do not disappear but will only move to other countries without such policy interventions and with lower production costs. In the end, products produced by high-emission industries will return to their home country in the form of imports, and the country's "carbon emissions trade deficit"[1] would widen.

In the US, the amount of carbon emissions contained in the country's imported goods grew over 1990–2008. Therefore, the country's "carbon emissions trade deficit" also widened (Fig. 2.4).

From a global perspective, moving high-emission industries to other countries is a "zero-sum game", and this is a process of transferring carbon emissions rather than achieving carbon neutrality. This cannot fundamentally solve the issue of greenhouse

[1] A "carbon emissions trade deficit" means that a country's imported goods contain more carbon emissions than its exported goods, and a "carbon emissions trade surplus" means that a country's exported goods contain more carbon emissions than its imported goods.

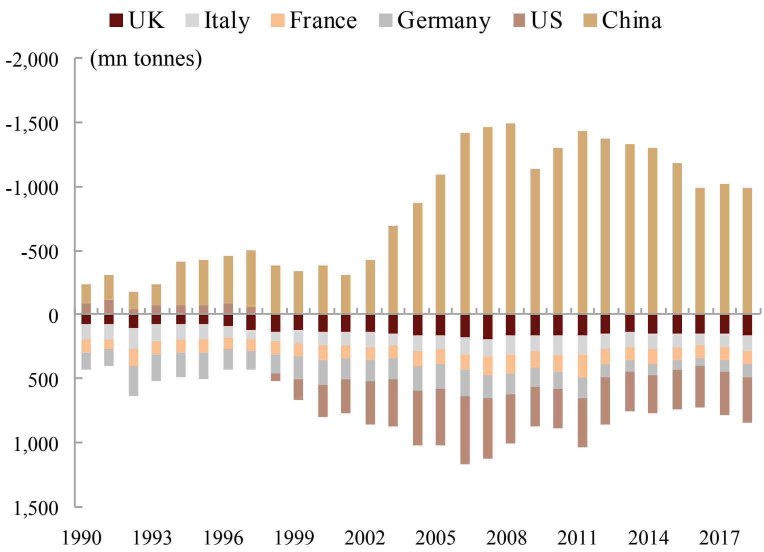


Fig. 2.4 Carbon emissions trade deficit/surplus. *Source* Our World in Data (based on Global Carbon Project), CICC Research

gas emissions because the damage to the environment is determined by the total amount of emissions rather than where the emissions came from. Therefore, it is not enough to just adjust the structure of industries and we must find a way to get to the root of the problem.

2.1.2 Approach 1: Raising Carbon Price to Internalize External Costs

The externality of environmental pollution is at the root of the carbon emission problem. To cope with the negative externalities of carbon emissions, the key is to introduce a carbon pricing mechanism and raise carbon prices. Carbon pricing means setting a price for carbon emissions (carbon price) to link the external costs of carbon emissions with emitters' private costs. Carbon pricing does not specify who should reduce emissions, where to reduce emissions, or how to reduce emissions. Instead, it provides an economic signal to emitters and allows them to decide whether to take measures to reduce emissions or continue to emit carbon dioxide and pay for their emissions. Carbon pricing works via two mechanisms: First, under the constraint of the carbon price, companies begin to regard emission permits as a factor of production, which could help to manifest the hidden costs of carbon emissions and internalize external costs. Second, carbon price could promote innovation in energy conservation and emission reduction technologies. Studies have found that higher carbon prices drive innovation in low-carbon technologies and increase companies' incentive to develop and adopt low-carbon technologies. The European Union (EU) is more experienced in carbon pricing at present.

2.1.3 Approach 2: Accelerating Innovation to Fundamentally Alter Mode of Production

Another way to achieve carbon neutrality is to fundamentally change the way companies operate, and specifically, **(1) by reducing the carbon emission intensity per unit of energy consumption, or (2) by reducing the energy consumption intensity per unit of GDP.** In this case, we have the following formula:

$$\frac{CO_2}{GDP} = \frac{CO_2}{E} \times \frac{E}{GDP}$$

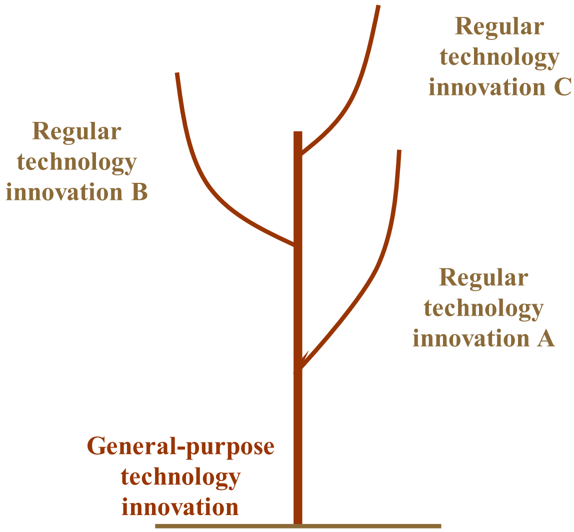
CO_2 represents carbon dioxide emissions, E represents the consumption of the energy, the first term on the right-hand side of the equation is carbon emissions per unit of energy consumption, and the second term is energy consumption per unit of GDP.

Innovation is crucial to reducing the two parts of intensity. Environmental protection-related technological innovation is usually called "eco-innovation" in the academic world. For example, the development of new emission reduction technologies and carbon capture technologies can reduce carbon emissions per unit of energy, while the use of clean energy can reduce energy consumption per unit of GDP. When promoting development of the low-carbon economy, many developed countries would focus on how to promote environmental technological advancement, and encourage and facilitate innovation.

In the longer term, innovation can not only solve the problem of carbon emissions but is also the major driving force for economic growth. Each technological revolution has reshaped the global economic landscape, and countries with an early start to innovation eventually achieved economic advances.

Unlike innovation in regular technologies, eco-innovation is a general-purpose technology innovation that has great effects on improving the productivity of the human society. The core feature of general-purpose technologies is the wide range of applications, and they could often be used as inputs by downstream industries, promoting innovation in the field where they are used. In addition, this type of technology also has large potential for improvement. Therefore, when innovation in general-purpose technologies emerges, it tends to be more conducive to the improvement of total factor productivity of the whole economy than regular technologies (Fig. 2.5). It is believed that eco-innovation, just like the invention of the steam engine and electric motor, could also trigger an important technological revolution in the history of human development (Fig. 2.6).

Fig. 2.5 General-purpose technologies drive other innovations. *Source* Gartner, CICC Research



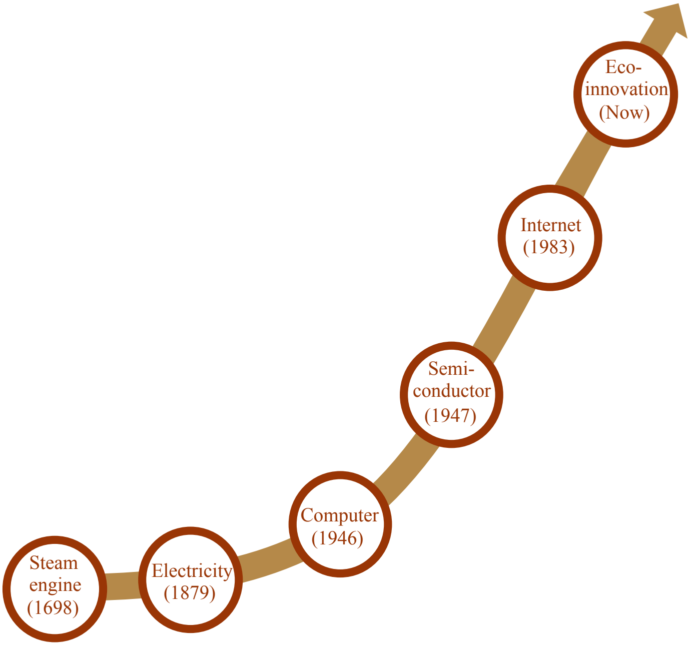


Fig. 2.6 Eco-innovation has potential for leading a new round of technological revolution. *Source* NASSCOM Insights, CICC Research

2.1.4 Multiple Barriers to Eco-Innovation

Although innovation could help to achieve carbon neutrality, technological progress could be relatively slow and face considerable uncertainty. If history is any guide, the development of a new technology usually traces an S-shaped curve from the stage of invention to the stage of application. That is to say, the development process of a new technology would accelerate from a low level first before it gradually slows down. It seems that the process of eco-innovation is slower than the development of regular technologies. In the early 1990s, some scholars believed that eco-innovation and internet technology represent the most promising directions of technological development in the future. In the past three decades, internet technologies have experienced exponential growth, but the overall progress of eco-innovation has been slow.

The slow development of eco-innovation could be due to the issue of double externality. The externality of environmental issues lies in the fact that the benefits from releasing pollutant emissions are enjoyed by companies, while the costs are borne by the whole society. The externality of innovations lies in that new technologies and products developed by companies can be easily imitated by their competitors so that the latter can gain the benefits of R&D, but the developers bear the R&D costs. As eco-innovation is both environmentally friendly and innovative, it features double externalities. Under the market mechanism, this would ultimately lead to insufficient investment in eco-innovation, which slows down the development of eco-innovation. Polzin (2017)[2] did in-depth research on barriers to eco-innovation. Specifically, eco-innovation faces multiple barriers such as technological, institutional, financial, economic, political and transformation barriers (Table 2.1).

2.1.5 Innovation-Related Policy Suggestions

How to remove the barriers above? One could address this issue from the following perspectives.

First, compared with developed economies, financial support channels at the innovation stage are not well-developed in China, so it is imperative to promote green finance. Second, promoting eco-innovation requires policy intervention, and policy departments should collaborate to form a joint force. Third, from a global perspective, removing political barriers requires the international community to reach a consensus, identify a more consistent development direction and vision, and then systematically promote eco-innovation policies under the framework of intergovernmental cooperation. In general, in order to accelerate eco-innovation, the government needs to introduce a series of tools and policy mechanisms, including government-enterprise R&D partnership, goal-driven public investment, demand stimulation,

[2] Polzin (2017), Mobilizing private finance for low-carbon innovation–A systematic review of barriers and solutions, Renewable and Sustainable Energy Reviews.

Table 2.1 Barriers to capital support for eco-innovation along the innovation process

Private finance instruments and structures					
Private research grants by firms (corporates)	Private development grants by firms (corporates)	Business angels, family offices, crowdfunding	Own profits, Business angels, family offices, crowdfunding, venture capital	Own profits, VC, private equity (PE), spin-off, mezzanine fund, corporate debt	Own profits, PE, public equity, project finance, mezzanine fund, corporate debt
Technological barriers	Technological barriers	Technological barriers	Institutional barriers	Institutional barriers	Institutional barriers
	Economic barriers	Economic barriers	Economic barriers	Economic barriers	Economic barriers
		Financial barriers	Financial barriers	Financial barriers	
Political barriers	Political barriers	Political barriers	Political barriers	Political barriers	Political barriers
		Transformation barriers	Transformation barriers	Transformation barriers	
Basic R&D	**Applied R&D**	**Demonstration**	**Pre-commercial**	**Niche market & supported commercial**	**Fully commercial**

Source Friedemann Polzin (2017), Mobilizing private finance for low-carbon innovation—A systematic review of barriers and solutions, Renewable and Sustainable Energy Reviews, CICC Research

and tax system reforms to break the "lock-ins" and path dependence that hinder eco-innovation. Policies should be introduced to eliminate the advantages of traditional energy sources under the free price system, achieve the internalization of externalities, and encourage the transfer of social resources from conventional technologies to a green economy.

2.1.6 *Approach 3: Improving the Social Governance System and Encouraging Emission Reduction Among the General Public*

Innovation is very important for achieving carbon neutrality, but eco-innovation faces multiple barriers and does not happen overnight. Therefore, to achieve carbon neutrality, efforts must also be made to improve social governance. Such efforts include formulating corporate governance standards compatible with a low-carbon world, building an environmentally friendly financial system, improving carbon tax and carbon market systems, encouraging low-carbon lifestyles, and advocating new consumption concepts. These efforts could help reach a consensus on environmental protection and promote carbon neutrality among the general public. For example, garbage classification, shared mobility services, and reducing electricity use at home can help to cut carbon emissions. Such efforts do not necessarily require new technologies and may simply require emitters (mainly consumers) to adopt low-carbon

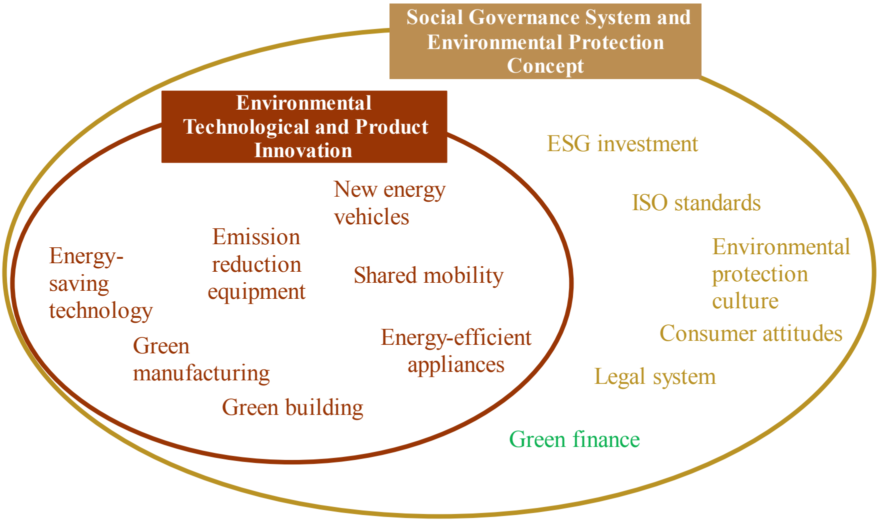


Fig. 2.7 In addition to innovation, efforts must be made to improve social governance. *Source* CICC Research

lifestyles. Therefore, improving the social governance system and raising public awareness of environmental protection will play an essential part in promoting carbon neutrality (Fig. 2.7). We will elaborate on it in the following sections.

2.2 Issues Related to Fairness

2.2.1 Distribution of Income

Carbon neutrality also has global negative externalities. If only a single country strives to achieve carbon neutrality, energy consumption intensity may be negatively impacted in the short term. A single country's efforts to reduce emissions often cannot offset the unrestricted emissions of other countries. Instead, this could push up costs and damage the competitiveness of related industries in the country, while other countries may benefit. Domestically, fairness regarding carbon neutrality is related to the issue of income distribution, including the distribution of income between different income groups and between different generations.

Distribution of carbon neutrality cost between different income groups: Carbon tax is "regressive" and may add burden to the low-income group. Given the low elasticity of demand for fossil fuels and the high proportion of direct and indirect spending on fossil fuels by the low-income group, the low-income group may bear a higher proportion of cost when prices of fossil fuels rise driven by carbon prices. Carbon tax "regressivity" is related to consumption baskets of different income groups, but a deeper reason is that carbon taxes are indirect taxes and could be easily passed on. As for solutions, one method is to reduce the use of carbon tax and rely more on carbon trading to raise carbon prices. However, carbon trading also can be regressive as it essentially adds constraints on production. The other method is to increase tax rebates and compensate low-income groups with the carbon taxes collected. For example, 15% of the Regional Greenhouse Gas Initiative's (RGGI) proceeds from the auction of carbon dioxide allowances are used to subsidize low-income groups' energy expenditures to mitigate their economic pressure from rising energy costs.

Distribution of carbon neutrality cost between different generations: The present generation may bear the majority of the cost of carbon neutrality, while the previous generation and the next generation could benefit more. If carbon neutrality is achieved, the next generation will benefit more from the improving environment and economic growth. However, the investment to achieve carbon neutrality will be mainly made by the present generation. The present generation may bear the majority of the cost of carbon neutrality. Therefore, the next generation is likely to benefit more than the present generation on the road to carbon neutrality (Fig. 2.8). To balance the costs and benefits between the two generations, the government should transfer payment across different periods. For example, the government could issue green bonds to finance carbon neutrality-related public investment, and the present generation and the next generation could jointly repay the interest and principal of the bonds.

The fairness issue also exists between the present generation and the previous generation. For example, the majority of the environmental pollution today is related to the production and life activities of the previous generation. We have calculated the ultimate distribution coefficient (the consumption of a product to produce a unit of another final product) for the electric power, heat generation and supply industries that contributes most to carbon emissions. We find that the residential property construction sector has the highest distribution coefficient (Fig. 2.9). In

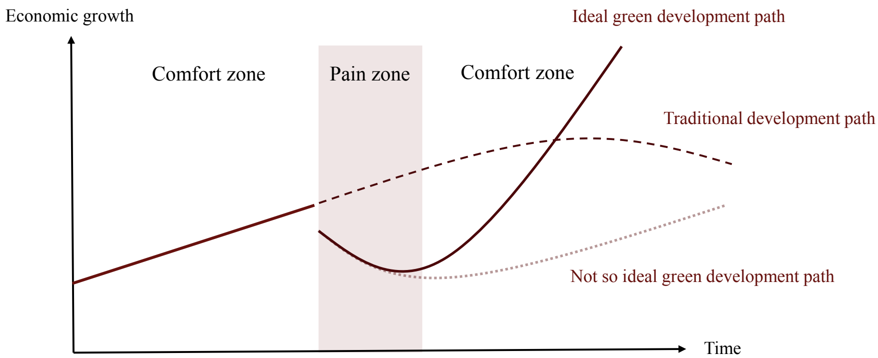


Fig. 2.8 Next generation to benefit more than present generation on the road to carbon neutrality. *Source* CICC Research

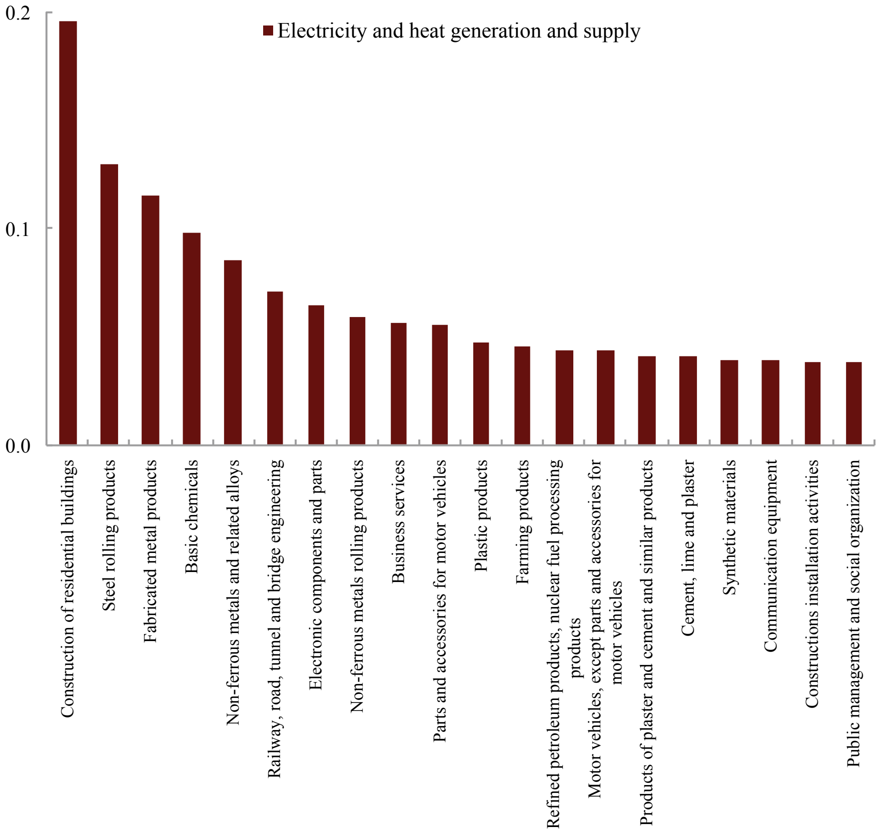


Fig. 2.9 Ultimate distribution coefficient of the electric power, heat generation and supply industries. *Note* Coefficient value on the y-axis. *Source* Input–output tables of China (2018), CICC Research

other words, the real estate industry consumes the most electric power and heat. Therefore, property owners should bear more "historical responsibility" to reduce carbon emissions. In this regard, perhaps a proper amount of taxes should be levied on property owners with "high-carbon assets."

2.2.2 *How to Share the Cost of Emission Reduction Among Industries and Regions?*

Carbon neutrality also involves the issue of cost sharing among different industries and regions within a country, and the issue of direct and indirect carbon emissions. In 2017, eight major industries accounted for nearly 90% of carbon emissions in China. The power industry (mainly thermal power) accounted for the largest share (44.4%), followed by the steel industry (18.1%), the construction materials industry (12.6%), the transportation[3] industry (7.8%), the chemicals industry (2.6%), the petrochemicals industry (1.5%), the nonferrous metals industry (0.7%), and the papermaking industry (0.3%). Power and steel industries are major contributors to the overall growth in the proportion of carbon emissions by the eight major industries, while the proportions of carbon emissions by other industries among the eight industries have been relatively stable. So, should these eight industries bear the majority of the cost of emission reduction? Obviously, these eight industries are only industries with high levels of direct carbon emissions, and the output of these eight industries is mainly used as intermediate input by other industries. Without the output of these industries as intermediate input, other industries may not be able to operate normally. Thus, the eight major industries should not be responsible for the entire cost.

From the perspective of geographical regions, China's fossil energy supply is more concentrated in the north of the country. Fossil energy production in China is mainly concentrated in provinces such as Shanxi, Inner Mongolia, and Shaanxi. Specifically, coal production is mainly concentrated in provinces such as Inner Mongolia, Shanxi, and Shaanxi; crude oil production is mainly concentrated in provinces and municipalities such as Shaanxi, Heilongjiang, and Tianjin; and natural gas production is mainly concentrated in provinces and municipalities such as Hebei, Shanxi, and Shandong. Historical experience suggests that restrictions on fossil energy sources often lead to employment problems. For example, the number of employees in China's mining industry has rapidly decreased from the peak level of 6.36mn in 2013 to 3.68mn in 2019 due to environmental protection-related production restrictions. Although the rapid growth of emerging service industries in the past several years can create new employment opportunities, it is often difficult to achieve stable employment transfer due to different technical thresholds between new and traditional industries, and the mismatch in regional distribution of industries.

The impacts of emission reduction on local government finances also should not be ignored. Fiscal revenues are highly dependent on mining and power industries in provinces such as Shanxi, Inner Mongolia, and Shaanxi, indicating that carbon neutrality may have a larger impact on these provinces (Fig. 2.10). On the one hand, fiscal policies should play a role in transferring part of fiscal revenues generated by carbon pricing to these provinces to prevent their fiscal revenues from falling sharply (which may affect people's livelihood and debt repayment in these provinces), supporting the green transformation of industries in these provinces, and developing low-carbon and decarbonization technologies for industries in these provinces to promote carbon emission reduction. On the other hand, industrial policies should play a role in transforming and upgrading industries in coastal areas, and supporting and encouraging some industries to move to provinces with abundant fossil energy to prevent the hollowing out of industries and population outflows in such provinces. In addition, the ability to absorb and store carbon in China's terrestrial ecosystems

[3] Including airlines.

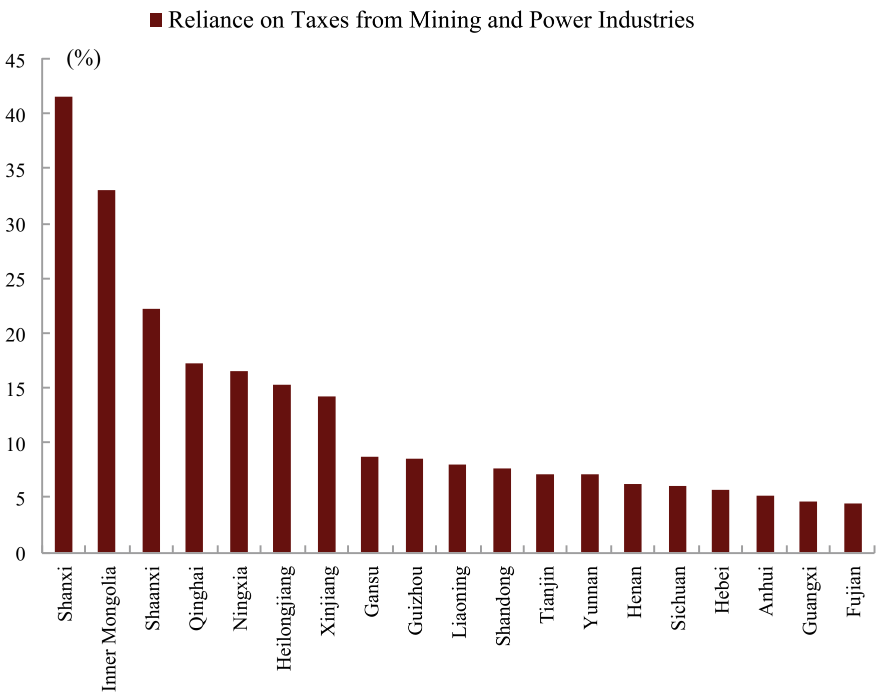


Fig. 2.10 Provinces with high reliance on taxes from mining and power industries. *Source* China Taxation Yearbook 2018, CICC Research

may be underestimated. Economies in the southwest and northeast of China are less developed. In our view, carbon sinks could play an important role in alleviating poverty, promoting carbon emission reduction, and facilitating the rebalancing of income distribution among different regions.

Chapter 3
The Capacity of Carbon Pricing Mechanism

Abstract From the perspective of policy tools to promote carbon neutrality, constructing a unified national carbon market may be one of the most important measures in 2021. The carbon market has drawn a growing amount of attention since China announced its aim to reach carbon emission peak before 2030 and achieve carbon neutrality before 2060. The Ministry of Ecology and Environment stated in September 2020 that the power generation industry is ready to be included in the national carbon market. Under these circumstances, China should accelerate the establishment of the carbon market over the 14th Five-year Plan period to include other key industries (e.g., the steel, cement, and electrolytic aluminum industries) in the market. As the official launch of the national carbon market is approaching, the topic of carbon market is ever-present in the discussions of policy instruments in promoting carbon neutrality. The carbon market appears to have become key to formulating policies for carbon neutrality. Such an inevitable move may imply that several important issues have been ignored, e.g., is it appropriate to include several different industries in one single carbon market? After carbon emission permits are granted to different production activities, should a unified carbon price be levied against different production activities? Would a unified carbon market produce any unexpected spillover effects? In addition to the carbon market, are there any similar or different carbon neutrality policy instruments that could be considered as more suitable choices? In this chapter, we analyze these issues based on the green premium concept and we draw several conclusions: (1) The power and steel industries are two major industries that are suitable for inclusion in the carbon market, while the carbon tax-based carbon pricing mechanism may be more suitable for the transportation, chemicals and construction materials industries; (2) Unified carbon pricing may not be appropriate, and differentiated carbon pricing should be adopted; (3) Compared with theoretical discounting of the social cost of carbon, "parity carbon cost" may be more suitable to be used as a reference for setting carbon prices in reality. In order to explain the logic behind these conclusions, we also discuss the following issues in this chapter: (1) We distinguish between carbon price concepts related to carbon neutrality, offering the basis for further discussion; (2) We analyze problems in the logic behind the idea of a unified carbon price, and we propose the idea of differentiated carbon prices based on the concept of net social cost; (3) From the perspective of green premium, we explore more realistic calculation methods for

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_3

differentiated carbon prices; (4) Based on the green premium concept, we discuss carbon pricing mechanisms that are suitable for different industries, and the establishment of trading mechanisms in the carbon market; (5) We discuss the possibility of lowering the green premium from the perspective of social governance.

3.1 Unified Carbon Price: Social Cost or Net Social Cost?

There are many similar carbon price concepts in different contexts, such as in theories, in policy discussions and on daily basis. The connotations of these concepts are clear in their respective contexts, but some ambiguities may arise in cross-contextual discussions, especially in the discussions of carbon pricing.[1] Therefore, the World Bank has distinguished and defined different concepts related to carbon price.[2] Among these concepts, carbon price refers to the price determined by transactions in the carbon market, as well as the carbon tax rate. Unless otherwise specified, the carbon cost in this chapter refers to the "social cost of carbon", which is the discounted value of the social cost of carbon in each period as Nordhaus et al. measured. US President Biden also used this definition of the carbon price when he announced the social cost of carbon calculation immediately after he took office.

In fact, this is not the first time the US government calculated carbon cost. The Obama administration calculated carbon cost in 2010, and carbon cost in 2020 was about US$26 per tonne of carbon based on the calculation back then[3] and US$42 per tonne of carbon based on the updated calculation in 2016 (Fig. 3.1). In 2017, the Trump administration updated the calculation of carbon cost again, and estimated the carbon cost in the US at only around US$7 per tonne of carbon.[4] US policymakers who oppose or advocate emission reductions both support their views by calculating carbon cost, reflecting the importance of carbon cost for carbon pricing. Since carbon pricing is regarded as the most important policy instrument to achieving carbon neutrality, the calculation of carbon cost can also be considered as an important foundation for carbon neutrality policies to some extent.

---

[1] http://www.nbd.com.cn/articles/2020-09-29/1514734.htm.

[2] World Bank stated in 2019 that "Carbon pricing puts an explicit price on greenhouse gas emissions expressed as a monetary unit per tonne of carbon dioxide equivalent (CO2e). The effective carbon rate is the sum of market-based instruments (specific energy taxes, carbon taxes and carbon emission permit prices) applied to carbon emissions. Explicit carbon pricing meanwhile puts a price directly on greenhouse gas emissions. Two instruments that fall into this category are the carbon tax, which is a price-based instrument and the emissions trading system, which is a quantity-based instrument. Implicit carbon pricing is used in a variety of ways and refers to policies that impose compliance costs (i.e. an implicit price) on activities that emit greenhouse gases. Internal carbon pricing is when organizations assign a monetary value to greenhouse gas emissions in their policy analysis and decision making."

[3] Technical Support Document: Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, February 2010.

[4] Brad Plumer, Trump put a low cost on carbon emissions. Here's why it matters. The New York Times. August 2018.

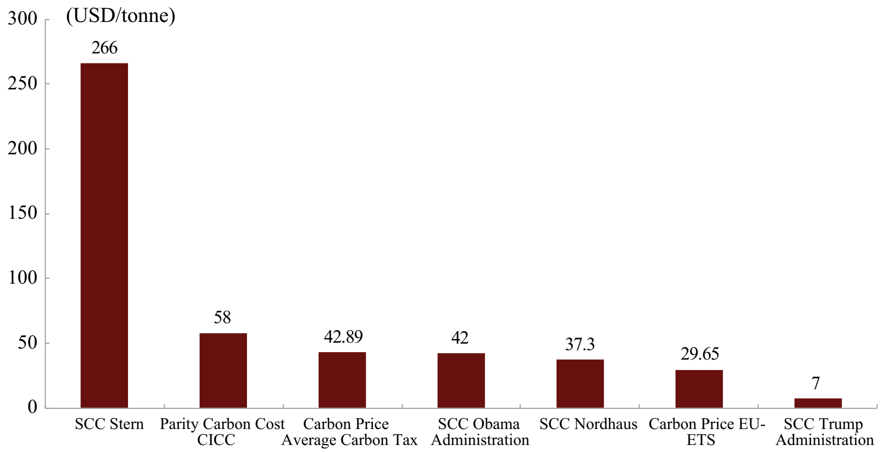


Fig. 3.1 Carbon cost and carbon price (US dollar per tonne of carbon).[5] *Note* The "parity carbon cost" is the parity carbon cost in China calculated based on the green premium in 2021. The carbon price (EU ETS) is the arithmetic average of the spot transaction prices in the European Union's carbon trading market in 2020. The "average carbon tax" is the average value of carbon taxes in each country calculated based on World Bank data in 2020. *Source* Nordhaus (2016), World Bank, EEX, CICC Global Institute

However, policymakers have not reached a consensus on the important fundamental data usage (i.e. carbon cost), and scholars also have different views on the calculation of carbon cost. For example, climate economist William Nordhaus estimated carbon cost at about US$37 per tonne of carbon in 2020.[6] Nicholas Stern, an economist in the field of carbon cost calculation who hold different views from Nordhaus, estimated the carbon cost at about US$266 per tonne of carbon.[7] The parity carbon cost in China calculated by us based on the green premium is around Rmb377 (about US$58) per tonne of carbon. Why do different calculation methods derive such different carbon costs for the same carbon emissions? From what perspective should we comprehend carbon cost? Why should we calculate carbon cost from the perspective of green premium? What are the implications for carbon neutrality policies?

To explore these questions, it would be necessary to discuss externalities. In 1920, the British economist Arthur Pigou conducted a groundbreaking study on the issue of externalities. Almost all of the current mainstream carbon cost calculation methods can be traced back to Pigou's idea of the internalization of social costs. The theory is simple and clear, but the calculation methods at the technical level are very complicated and different. An important difference between Nordhaus and Stern comes from their highly different views on discount rate (see Fig. 3.2). The

[5] For the sake of brevity, "tonne of carbon" is used in this chapter to represent "tonne of carbon dioxide." Unless otherwise stated, carbon prices below are in renminbi terms.

[6] William D. Nordhaus, Revisiting the social cost of carbon, November 2016.

[7] William D. Nordhaus, Revisiting the social cost of carbon, November 2016.

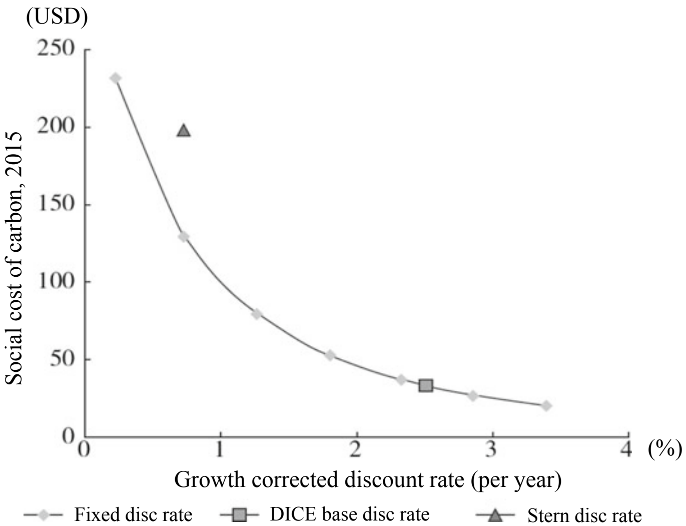


Fig. 3.2 Carbon cost and discount rate. *Note* "DICE base" represents the discount rate adopted by Nordhaus in 2016 and the corresponding carbon cost; "Stern" represents the social cost of carbon derived with the discount rate in "The Stern Review". *Source* Revisiting the social cost of carbon by William D. Nordhaus, CICC Global Institute

Obama administration and the Trump administration not only had different views on discount rates but also had different views on the scope of coverage: the former calculated global carbon cost, while the latter only calculated the social cost of carbon in the US.

The Obama administration used three different methods to calculate carbon cost, namely the Dynamic Integrated Climate and Economy (DICE) model, the Policy Analysis of the Greenhouse Effect (PAGE) model and the Climate Framework for Uncertainty, Negotiation, and Distribution (FUND) model. Among them, the DICE model is the most fundamental one. In this endogenous growth model, carbon dioxide affects temperature and thus overall economic output, but it does not factor in the carbon emissions' impacts on various other economy components. The PAGE model and FUND model make up for this deficiency to a certain extent, and they respectively factor in the structural differences of carbon emissions' impacts on different geographic regions and different industries.[8]

However, behind these seemingly serious differences, it seems that a question has been intentionally or unintentionally ignored: Should carbon costs be differentiated in different industries? Based on current mainstream calculation methods, there is only one carbon cost among all sectors in an economy. Since carbon cost is an important basis for carbon pricing, such a unified carbon cost calculation that does not factor in differences of industries seems to have produced an important impact on the logic of carbon pricing in reality that a unified carbon cost implies a unified carbon

[8] Pigou A C, *The Economics of Welfare*. Macmillan, New York, 1920: 193–194.

price. For example, as of 2020, the world's largest carbon trading market, the EU Emissions Trading System (EU ETS), covered 14 industries such as the power and transportation industries, and these industries have a unified carbon price in the same market. There is a similar situation in China. The country's upcoming national carbon market mainly covers the power industry at present and will also cover industries with high carbon emissions such as the steel, cement, and electrolytic aluminum industries in the future. This seems to mean that these different industries may have a unified carbon price after they are included in the national carbon market.[9]

However, is the idea of a unified carbon price implied by mainstream carbon cost calculation methods appropriate? Pigou's argument is still useful for thinking about this question. He believes that "All such effects must be included—some of them will be positive, others negative elements— in reckoning up the full physical net product of the marginal increment of any volume of resources turned into any occupation.[10]" In other words, what Pigou is actually discussing is not the social cost, but the net social cost as the difference between social cost and social benefit.

Ronald Coase, another economist who has done in-depth research on externalities, questioned the feasibility of Pigouvian tax in his masterpiece article *The Problem of Social Cost* (published in 1960), but he clearly wrote: "the problem is to devise practical arrangements which will correct defects in one part of the system without causing more serious harm in other parts.[11]" In other words, Coase's perspective on externalities is still a concept of net social cost.

Due to the difference between social cost and net social cost, it seems that there should be a certain degree of skepticism about the idea of a unified carbon price. Such a carbon cost analysis based on net social cost rather than social cost could be extended in a more general way. This means that different carbon price levels should also be applied to industries with different social benefits. So, can we infer that it may not be appropriate to calculate the same carbon cost for industries with different net social costs? Then a more practical question may emerge: For carbon pricing in reality, is it appropriate to include industries with different net social costs in a unified carbon market to bear the same carbon price determined by transactions, or is it appropriate to set the same carbon tax rate for different industries with different net social costs?

So far there is a big controversy over the differentiated carbon prices system. There are two major issues. First is the argument about efficiency: why do products such as gas and automobiles use a unified carbon price decided by the market, but products such as the carbon mission rights use differentiated carbon prices? Second is the

---

[9] The Ministry of Ecology and Environment stated in September 2020 that the power generation industry is ready to be included in the national carbon emissions trading market, and that China should accelerate the establishment of the carbon emissions trading market over the 14th Five-year Plan period to include other key industries (e.g., the steel, cement, and electrolytic aluminum industries) in the market.

Source: http://www.mee.gov.cn/ywdt/hjywnews/202009/t20200927_800752.shtml.

[10] Pigou A C, *The Economics of Welfare*. Macmillan, New York, 1920: 115–116.

[11] Coase R H, The Problem of Social Cost, *Classic Papers in Natural Resource Economics*. Palgrave Macmillan UK, 1960.

argument about fairness, which indicates that the differentiated carbon prices violate the principle of fairness, and lead to arbitrage problems such as carbon leakage.

For the first issue, we recommend thinking from the externality perspective. When we talk about ordinary goods such as gas and automobiles, we don't have to consider the externality issue because the market is efficient for these products, so it is logical to let the market determine the price. However, when carbon emission rights become a special good in an inefficient market, the pricing of such a good needs to consider its externalities. Externalities exist when the free market fails or when the market cannot determine the price, so it is not suitable to compare carbon emission rights with general goods in the market. More importantly, when we consider these externalities, why should we only account for the negative externality and neglect the positive externality? Of course, if we don't take the externality effect into account, then the social return problem doesn't exist either, and we can simply use the free market to determine the price for general goods. Thus, an economic activity with externalities that has different net social costs in different industries may require differentiated pricing.

From the perspective of new institutional economics, another problem worth mentioning is that market pricing is not necessarily efficient. Whether we use administrative or market allocation to allocate resources, the transaction cost will greatly affect the efficiency of pricing. For an ordinary good, the market is efficient due to the lack of externalities. Nonetheless, carbon emissions are different. EU ETS was not formed because of the economic incentives. Instead, the establishment of the market itself can be considered as the correction of excessive spontaneous profit-seeking behaviors. Furthermore, the operations of the market mainly rely on the compulsory forces from the government. As a result, the transaction cost is higher under the EU ETS than that of the carbon tax. In this context, it is hard to say the carbon market has higher pricing efficiency than that of the carbon tax.

Therefore, to simply regard carbon emission as an ordinary good, or to overemphasize a unified carbon price may be questionable. If we disregard the fact that the carbon price derives from the externality of carbon emissions, and consider the carbon emission as an ordinary good that lacks externality, it may cause a theoretical dilemma: now that a unified carbon price is justifiable in one economy, why can't we have a unified carbon price among different economies? On a practical level, if we match the carbon price among developing countries and developed countries, it would impose extensive cost to developing countries. From a solely theoretical point of view, although the social costs imposed to all countries are the same from carbon emissions as a global externality, developing countries have larger populations and more urgent needs to improve their living environments through economic growth. Therefore, the social benefits of carbon emissions for these countries are higher than those of developed countries. This means that although the social cost of the same carbon emissions in different countries is the same, the net social cost of developing countries should be lower. Thus, it is logical to say that simply requiring developing and developed countries to use a single unified carbon price is unreasonable.

For the second question we mentioned above, it involves a value judgement question: what is fairness? Fairness has two perspectives: the private economic perspective and the public economic perspective. We can take one question into consideration: if we see carbon emission price as a punishment, does it mean that carbon emissions from different economic activities should bear various degrees of punishment? For example, let's compare a person mining bitcoin and a large number of people who burn coal for heating on cold winter days. In this case, both actions create emissions. Should both of them be covered in the carbon market to get the same carbon price and level of punishment? From the social cost perspective, one unit of carbon leads to the same level of harm to society, and thus calls for the same punishment regardless of energy use for heating or bitcoin mining. If they are punished differently, from the private economic perspective, it indeed seems unfair. However, it is obvious that emitting large amount of carbon to "dig" a currency that could have been easily printed produces very different social benefits from saving lives under extreme temperatures. Hence, punishing the two activities in the same way is unfair from the public perspective.

In addition, the so-called carbon leakage seems like an inequality issue caused by the differential price. However, it is one of the most common industrial policies to promote balanced regional development through differential pricing of production factors, such as regional tax incentives, export tax rebates for different industries, and distorting polices as differentiated pricing for inclusive finance. These policies seem to distort the fairness in market competition, but they actually contribute to social fairness in a broader sense. The question is, in reality, how can we achieve optimal carbon pricing arrangements? In the next section, we apply this question to green premium.

3.2 Green Premium and the Choice of Carbon Pricing Mechanisms

As mentioned earlier, it is reasonable to think about carbon pricing in terms of social net cost rather than social cost. However, whether it is based on social cost or net social cost, carbon price is a concept that is theoretically feasible. In reality, it is difficult to calculate and possibly subject to large errors. In addition to the above-mentioned discount rate, the greater dispute lies in how to define the social cost. As Stern has put forward: (1) Causes and consequences of climate change are global, and the economic harm caused by the emission of the same equivalent of carbon dioxide has nothing to do with regions. (2) Greenhouse gases may remain in the atmosphere for hundreds of years and there will be a lag in the impact of accumulated emissions. (3) Greenhouse gases' potential impacts on human society are uncertain and difficult to estimate.[12]

Even after making various assumptions about the discount rate and social cost, calculation is still very difficult. Taking the calculations by the Obama administration

[12] Nicholas Stern, *The Economics of Climate Change the Stern Review*, Cambridge University Press 2007.

as examples, three models not only simulate the scenarios of three discount rates (5%, 3%, and 2.5%), but the initial settings of each specific calculation model also contain some randomly generated parameters. To alleviate the unreliability of results caused by this, each model has repeated calculations 10,000 times. President Biden intends to spend a year and a half updating the carbon cost calculation.[13] This not only reflects the importance of carbon cost calculation under mainstream frameworks, but could also be because that the calculation process is highly complicated and uncertain, and requires a high input cost.

It is already so difficult to calculate one unified carbon cost based on social cost. If differentiated carbon costs of various industries are calculated from the perspective of net social cost, the related disputes in definition of carbon costs, and the time and resources required in the calculation process may be much greater than those for the unified carbon cost. However, despite of the difficulty in calculation, the above analysis on net social cost shows that it is indeed necessary to calculate different carbon costs for different industries. Therefore, it is necessary to think about how to calculate differentiated carbon costs in a more feasible way outside the mainstream framework and how to promote it in reality.

There are two ways to set the carbon prices. One method still uses the carbon market as the only pricing mechanism and complemented by operational design to arrive at a differential carbon price, e.g., issuing more quotas for industries with lower net social cost, or transfer the auction revenue to the industries with lower net social costs. Obviously, these approaches contribute to the *de facto* differential carbon price, but also distort the so-called fair competition. In other words if the distorted mechanism is used to realize the differential carbon price, then the questioning of the differentiated carbon prices system may be untenable in the first place.[14]

The other way is to rethink the single pricing approach relying on carbon market. In this aspect, the green premium could give us some hints. The green premium is essentially a kind of carbon cost parity which requires emitters to pay additional costs for carbon emissions to ensure that the emitters' production costs are equal to the production costs with the clean energy and put emphasis on using carbon neutrality technologies to solve the problem of carbon emissions in the future.

Therefore, green premium based on reality seems to have greater practical significance than mainstream carbon costs in theory. More importantly, green premium can reflect the policy implications of differentiated carbon costs and differentiated carbon pricing from the perspective of net social cost. Next, we will discuss how to achieve carbon pricing based on the framework of green premium, which mainly includes three aspects: (1) Should different industries adopt different carbon pricing mechanisms? (2) Should different industries have different carbon price levels? (3) If there is a need to set differentiated carbon prices, is there a differentiated carbon price benchmark for each industry?

---

[13] White House, Executive order on protecting public health and the environment and restoring science to tackle the climate crisis, January 20, 2021.

[14] As there are opinions oppose to set the differential carbon price mechanism at first.

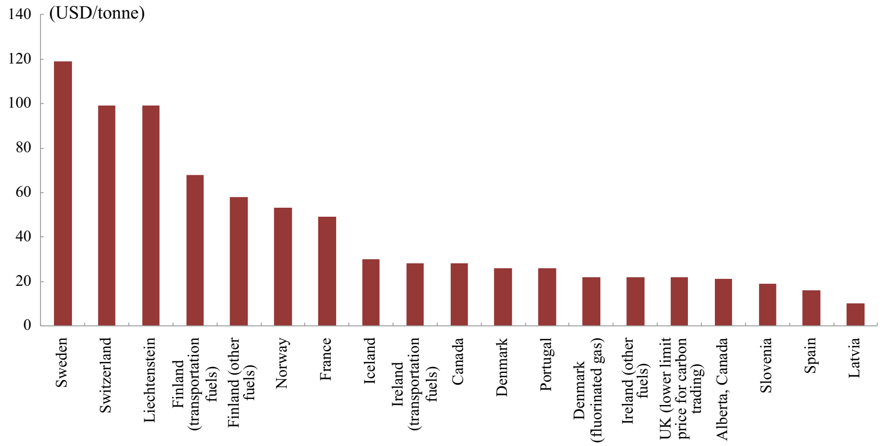


Fig. 3.3 Carbon tax rates in various countries (US$/tonne of carbon). *Note* Data as of November 2020. *Source* World Bank *State and Trends of Carbon Pricing 2020*, CICC Global Institute

3.2.1 Pigou Versus Coase: Similarities and Differences Between Carbon Tax and Carbon Market

The theoretical foundations of carbon tax and carbon market, two basic carbon pricing mechanisms, come from Pigou and Coase separately. Although both analyze externalities from the perspective of net social cost, their views on how to realize the internalization of net social cost are not the same. Pigou's solution is Pigouvian tax. Coase believes that the Pigouvian tax is an idea that is difficult to realize, because it is difficult to know what the right tax rate is. He proposes the pricing of externalities through free-market transactions after clarifying property rights.

In practice, as of 2019, there were 31 carbon trading mechanisms and 30 carbon tax mechanisms implemented or scheduled around the world. Specifically, the representative countries that levy carbon taxes were mainly the Nordic countries like Finland and Norway.[15] Currently, the largest carbon market in the world is EU ETS, and the Regional Greenhouse Gas Initiative (RGGI) in the US is also a carbon trading mechanism. We analyze the similarities and differences between the two pricing mechanisms from three perspectives, i.e., emission reduction effects, transaction costs, and the use of public revenue. In the end, we explore the applicability of the two pricing mechanisms to China in light of green premiums.

Carbon tax rates in different countries or regions are shown in Fig. 3.3, and prices of carbon emission allowance futures in the EU ETS are displayed in Fig. 3.4.

[15] World Bank, *State and Trends of Carbon Pricing 2020*, 2020, May 27.

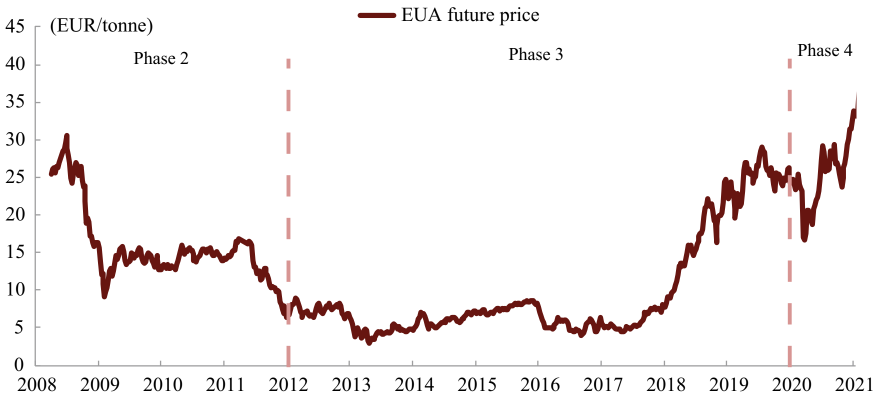


Fig. 3.4 EU ETS carbon emission allowance futures prices (EUR/tonne of carbon). *Note* Data as of March 2021, EU ETS has four phases: phase 1 is 2005–2007, phase 2 is 2008–2012, phase 3 is 2013–2020, phase 4 is 2021–2030. *Source* ECX EUA futures from ICE, CICC Global Institute

3.2.1.1 Compared to Carbon Tax, Carbon Trading Has More Certain Effects on Emissions Reduction

Both carbon tax and carbon trading could help reduce carbon emissions by increasing the cost of carbon emissions. However, there are still some differences between the two from the perspective of internal logic of operating mechanisms. Carbon tax is essentially a fixed carbon price determined in advance. Therefore, market participants can form relatively stable expectations for returns on R&D and investment in emissions reduction technologies. The mechanism is conducive to promoting innovation, but it remains uncertain whether such a mechanism can effectively reduce emissions.

Because as long as the benefit of increasing one unit of carbon emissions can cover the cost of carbon tax, enterprises will continue to increase carbon emissions. This situation has also been evidenced by empirical analysis of the emission reductions in Nordic countries such as Sweden and Norway from 1981 to 2007. Compared with the baseline scenario in which no carbon tax is levied, the imposition of carbon tax reduced emissions by approximately 2.8%–5%. In addition, the absolute amount of emissions in the four Nordic countries, i.e., Finland, Denmark, Sweden, and Norway, did not show a significant decline after the imposition of the carbon tax, or the drop was significantly smaller than that after joining the carbon market (Fig. 3.5).

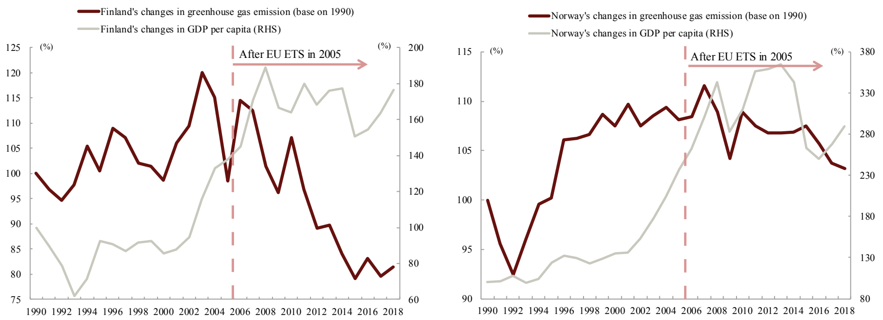


Fig. 3.5 Carbon emissions and GDP per capita in the Finland and Norway. *Source* European Environment Agency (EEA), CICC Global Institute

Compared with carbon tax, which lacks constraints on total emissions, the control over total emissions under the carbon trading mechanism provides a better solution in this regard. Since the upper limit of carbon emissions is set in advance, even in the case of an overheating economy, the ultimate amount of carbon emissions is still unlikely to exceed the predetermined cap significantly. Therefore, a big difference between carbon market and carbon tax is that the former provides a relatively definite path to reducing carbon emissions. The EU ETS (Fig. 3.6) and the US RGGI (Fig. 3.7) basically confirm this argument.

However, this does not mean that the carbon trading mechanism is perfect. In fact, compared to carbon tax, as a quantitative carbon pricing mechanism, the carbon market increases the certainty over carbon emission reductions, but creates uncertainties over carbon prices. In a pure carbon market, the supply of carbon emission permits is inelastic. Once economic fluctuations trigger changes in the demand for carbon emission permits, the demand-side shocks will be fully absorbed by carbon prices, which leads to highly volatile carbon prices in the carbon market. Highly

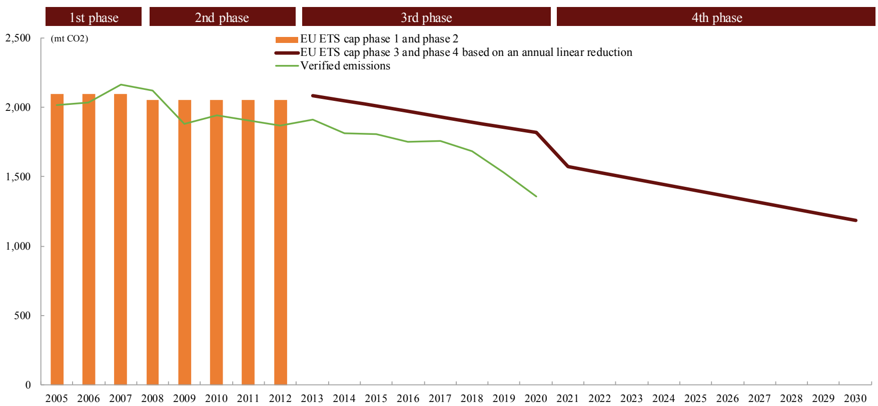


Fig. 3.6 EU ETS's emissions caps and the actual emissions. *Source* EEA, CICC Global Institute

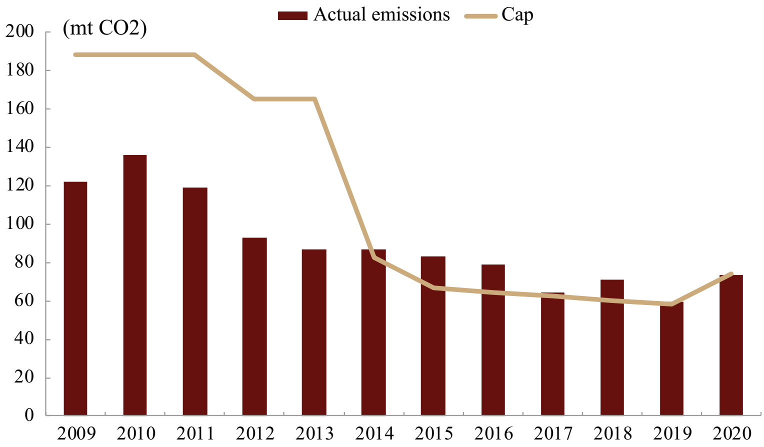


Fig. 3.7 US RGGI's emissions cap and actual emissions. *Note* In 2020, RGGI's coverage expanded from 9 states to 10, so the cap was raised. *Source* RGGI COATS, CICC Global Institute

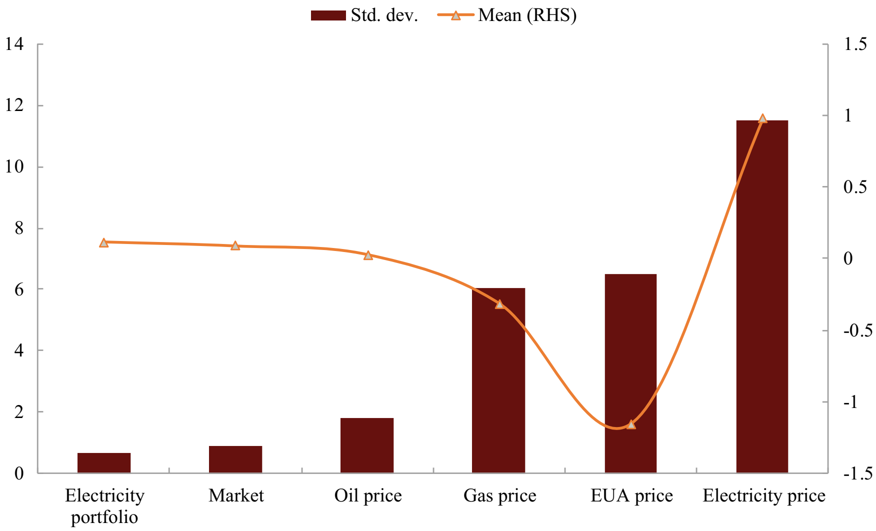


Fig. 3.8 EU ETS stage 1 (November 21, 2005–December 31, 2007): yields and standard deviations of several types of assets.[16] *Note* Right-axis represents average values. *Source* Yuan Tian et al. (2015), CICC Global Institute

volatile carbon prices mean that the expected returns on investment in low-carbon technologies are uncertain; this is not conducive to the development of technologies related to carbon neutrality. The asset yields and standard deviation of the first stage of the EU ETS are shown Fig. 3.8.

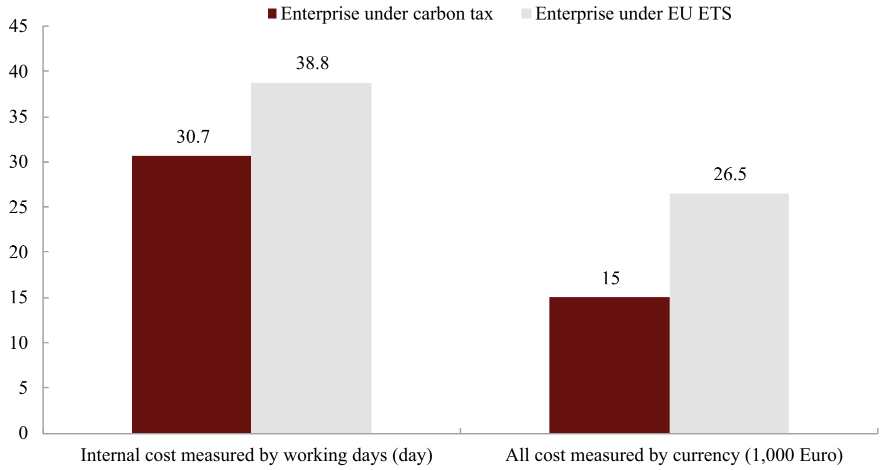


Fig. 3.9 MRV cost enterprises need to pay under two carbon pricing mechanisms. *Note* There are five types of companies participating in the survey: all companies subject to the requirements of the EU carbon tax MRV system, all companies subject to the requirements of the EU ETS MRV system, companies subject to both the EU carbon tax and ETS MRV system requirements, companies that are only subject to the requirements of the EU carbon tax MRV system, and companies that are only subject to the requirements of the EU ETS MRV system. Three types of cost are considered in the survey: the internal costs of management and actual work need to be undertake under MRV, measured by the time and money spent; the external costs, i.e., the costs of consulting services concluded in accordance with MRV regulations, measured by the money spent; capital costs, i.e., the costs of measuring, monitoring, recording, and data storage related to carbon emissions. *Source* Jessica Coria (2019), Transaction Costs of Upstream Versus Downstream Pricing of CO_2 Emissions, CICC Global Institute

3.2.1.2 Compared to Carbon Market, Carbon Tax Mechanism Lowers Transaction Costs

As new institutional economics emphasizes, the operation of the resource allocation mechanism also creates costs. Due to the inconsistent operation logic of the two carbon pricing mechanisms, there is a significant gap between their transaction costs as measured by monitoring, reporting and verification (MRV). As shown in Fig. 3.9, transaction costs in the carbon market are usually higher than those under the carbon tax mechanism. The main reason for such a difference is that the imposition of carbon tax relies on the existing taxation system, so there is no need to build a brand new dedicated MRV system.

In contrast, the carbon trading market is not an existing market formed spontaneously by profit-seeking economic entities, but a new dedicated market established with mandatory policies, such as legislation, as the institutional basis. Compared

[16] Yuan Tian, Akimov A, Roca E, et al., 2016, *Does the Carbon Market Help or Hurt the Stock Price of Electricity Companies? Further Evidence from the European Context*, *Journal of Cleaner Production.*

to the carbon tax-based pricing mechanism, the effective operation of the carbon trading market as a new deliberately created market requires more market entities besides carbon tax participants to work together, which will generate more coordination and supervision costs. On the one hand, in an artificially created market, the effective operation of the basic system does not depend on the market's genuine profit-seeking motivation, but on the enforcement of mandatory policies. This may require a large investment of resources. For example, the carbon emission allocation system, regardless of free allocation or fee-based, requires sufficient resources to monitor the process. Otherwise, the allocation process could easily become inefficient. On the other hand, in the carbon market, market participants not only comprise governments, carbon-emitting firms, and exchanges which serve as the infrastructure, but also intermediary institutions, a large number of institutional investors, and even individual investors introduced to improve pricing efficiency. In addition to spot products, there are also products such as futures and options. This means that the carbon market needs a new tailored MRV system to strengthen the supervision over participating entities. Increased interactions between participants also suggest higher transaction costs.

3.2.1.3 Distribution of Carbon Pricing Revenue: Carbon Tax Could Promote Fairness, While Carbon Trading Focuses More on Enhancing Efficiency

Regardless of whether the carbon tax or the carbon trading mechanism is adopted, there will be a carbon emission price. This, coupled with the transaction costs involved in the operations of the pricing mechanism, will cause two problems, i.e., weakening competitiveness of enterprises at the micro level, and carbon leakage at the macro level. A possible solution to these problems is to use the public revenue from carbon pricing reasonably. Public revenue is reflected as the government's tax revenue under the carbon tax mechanism, and the government's public revenue from the auction of carbon emission permits under the auction system. Theoretically, although these two types of revenues flow into the government through different channels, both can be used to solve the issues of weakening corporate competitiveness and carbon leakage caused by carbon pricing.

However, in practice, the use of public revenues from carbon taxes and the carbon market can still be somewhat different in terms of method of use. Concerning the use of revenues, as auction revenues from the carbon market are not directly included in fiscal revenues like carbon tax, the use of 78% of the auction revenues from the carbon market is subject to constraints in the form of legislation to avoid improper use of public revenues due to lack of fiscal discipline. However, the use of carbon taxes does not face such stringent constraints. Only about 43% of carbon taxes are used in legally stipulated ways. Because carbon taxes enter the government's fiscal system and are subject to existing fiscal disciplines, compared with the carbon market, there is no such strong need to impose additional constraints.

There are also some differences between the two in the final direction of revenue use. As the carbon tax directly enters the taxation system, they also reflect the attributes of public finance in terms of the final direction of use. More than half of the EU's carbon tax revenues in 2016 were used to support tax policies such as tax cuts and rebates (Table 3.1), with a portion used to reflect the pursuit of fairness in public finance. For example, Norway reduces taxes from other sectors when levying carbon taxes, and a portion of carbon tax revenues flow to government-funded projects[17] such as pension funds. The Canadian province of British Columbia stipulates that carbon tax revenues can be used to support low-income groups in a one-off tax rebate, which works as transfer payment.[18] The *Climate Action Rebate Act of 2019* introduced by the US Congress proposed to return 70% of the carbon fee to low- and middle-income residents through tax rebates.[19]

Unlike carbon taxes with public finance features, revenues from the carbon market are earmarked for specific uses. The auction revenues generated to reduce carbon emissions are mainly used to promote emissions reduction. According to OECD research, 86% of the carbon market's auction revenues face clear constraints on the direction of revenue use (78% through legal earmarking, 8% through political commitment). The No. 1 expenditure is the promotion of green travel (22%). For example, Canada promotes electrified mobility, Italy subsidizes low-carbon mobility, and California has started to build high-speed rail connecting major cities in the state. The second largest expenditure is to improve energy efficiency. For example, France and Italy have adopted energy-saving renovations for buildings for public institutions such as schools. In addition, a considerable proportion of revenues are used to support the development of renewable energy resources and subsidize green R&D. For example, half of the funds for the UK's Renewable Heat Incentive in 2016 came from auction revenues.[20]

The use of carbon taxes is not limited to the field of carbon neutrality. Carbon tax revenue has certain characteristics of public finance, and part of it can be used to support tax cuts in other areas, or transfer payments, etc., helping to promote fairness. Revenues generated by auctions in the carbon market are from carbon reduction, and used on carbon reduction. Expenditure mainly focuses on improving the efficiency of carbon neutrality, and to a certain extent, it helps reduce sharp price fluctuations' negative impacts on green investment and reduce the lack of motivation to innovate.

---

[17] OECD, *The Use of Revenues from Carbon Pricing*, 2019.

[18] Michael Maiello & Natasha Gural Illustrations by KELSEY DAKE. (n.d.). *The Tax that Could Save the World*. Retrieved January 31, 2021.

[19] https://taxfoundation.org/carbon-tax-bills-introduced-congress/. The bill was not passed.

[20] OECD, *The Use of Revenues from Carbon Pricing*, 2019.

Table 3.1 Constraints on use of the EU's carbon pricing revenues and expenditure structures in 2016

<table>
<tr><th>Constraints</th><th>Legal earmarking (%)</th><th>Political commitment (%)</th><th colspan="9">Type of constrained spending (%)</th></tr>
<tr><td rowspan="3">Carbon trading</td><td rowspan="3">78</td><td rowspan="3">8</td><td rowspan="2">Focus on energy efficiency</td><td rowspan="2">Support to renuewable energy use</td><td colspan="2">Promoting sustainable mobility</td><td rowspan="2">Subsidizing green R&D</td><td rowspan="2">Forestry, water, waste, land and biodiversity management, protection and conversation</td><td rowspan="2">Compensation to energy users</td><td rowspan="2">Other green spending</td><td rowspan="2">Others</td></tr>
<tr><td>Electric</td><td>Public</td></tr>
<tr><td>17.78</td><td>7.33</td><td>2.11</td><td>17</td><td>2.55</td><td>1.49</td><td>16.86</td><td>15.5</td><td>0.83</td></tr>
<tr><td>Carbon tax</td><td>43</td><td rowspan="2">22</td><td colspan="2">Tax policy changes (e.g. tax cuts, rebates)</td><td colspan="2">Green and environmental spending</td><td colspan="2">Energy and energy security spending</td><td colspan="2">Compensation to energy users</td><td>Others</td></tr>
<tr><td></td><td></td><td colspan="2">52.47</td><td colspan="2">0.11</td><td colspan="2">2.66</td><td colspan="2">2.17</td><td>3.87</td></tr>
</table>

Source OECD: The use of revenues from carbon pricing, CICC Global Institute

3.2.2 Carbon Pricing from the Perspective of Green Premium: Carbon Market to Be the Mainstay, with Carbon Tax as a Complement

Current choices of carbon pricing mechanisms seem to only focus on the share of emissions and emphasize the restriction of high-emission industries through the carbon market, which does not meet the requirement of differentiated carbon prices from the perspective of net social cost. Moreover, carbon tax and carbon pricing mechanisms have their respective advantages and disadvantages from the perspective of comprehensive emission reduction effects, transaction costs, and the use of public revenues, and there is no definite conclusion that one is better than the other (Table 3.2). As shown in the table below, it seems that carbon trading is indeed an ideal choice from the perspective of increasing the certainty of emission reductions alone. However, this also means that higher transaction costs may need to be paid, and in a society where the gap between the rich and the poor is widening, the opportunity to promote fairness through carbon tax would thus be lost.

More importantly, restricting carbon emissions through carbon market means that related industries will face greater uncertainty in carbon prices, which is less conducive to green investment and technological progress than under carbon tax. From the perspective of achieving carbon neutrality, carbon pricing is certainly one of the most important policy measures, but technological progress may be more decisive for ultimate success. In this sense, it is necessary for us to re-examine the logic of achieving carbon pricing through carbon market alone.

In this regard, the calculation of green premium can still give us some meaningful inspirations. The significance of green premium for carbon pricing is not only to support the concept of differentiated carbon prices under the net social cost theory, but also to measure the maturity of carbon neutrality technologies in various industries. Generally speaking, if an industry's green premium is high, it means that the industry's carbon neutrality technologies are not mature enough and that the

Table 3.2 Comparison of the advantages and disadvantages of carbon tax and carbon market

		Carbon tax	Carbon market
Effect on emission	Total emissions	Uncertain	Relatively certain
	Carbon pricing	Relatively certain	Uncertain
	Technological advancement	Relatively strong	Relatively weak
Transaction cost	MRV	Relatively low	Relatively high
Use of public revenue	Constrained revenue proportion	Relatively low	Relatively high
	Direction of use	Helps improve fairness	Focuses on emission reduction efficiency

Source CICC Global Institute

industry is in urgent need of promoting technological innovation. In this way, we can think about how to choose a carbon pricing mechanism from the dimension of green premium and share of emissions, to make better use of the advantages of the two pricing mechanisms to create a policy combination that is more conducive to promoting carbon neutrality in related industries.

Specifically, from the perspective of choosing carbon pricing mechanism, the above-mentioned 8 industries can be classified into 4 categories: the power and steel industries with high emissions and low green premiums, the construction material industry with high emissions and high green premiums, the transportation and chemical industries with low emissions and high green premiums, and the nonferrous metals, petrochemicals, and the papermaking industries with low emissions and low green premiums.

For the power and steel industries with high emissions and low green premiums, the two industries respectively have a green premium of 17% and 15.4%. This implies that carbon neutrality technologies in the two industries are relatively mature from an economic perspective, and the needs for technological innovation in these industries are not as urgent as those in industries with high green premiums. At the same time, emissions of these two industries account for 44% and 18% of total emissions, respectively, and their combined emissions account for 62% of the total (Fig. 3.10). Therefore, the power and steel industries are more suitable for adopting the carbon market-based carbon pricing mechanism. Such a carbon pricing mechanism can effectively promote the reduction of overall emissions, and there is no need to worry

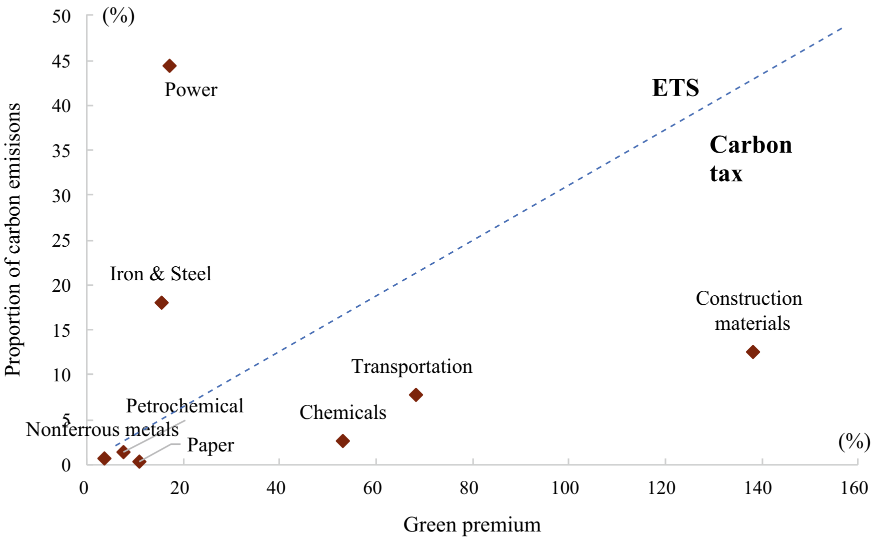


Fig. 3.10 Different choices for carbon pricing. *Note* Proportion of emissions is based on 2017 data, and the percentage of green premium is an estimate for 2021. *Source* CEADS, Wind Info, CICC Research

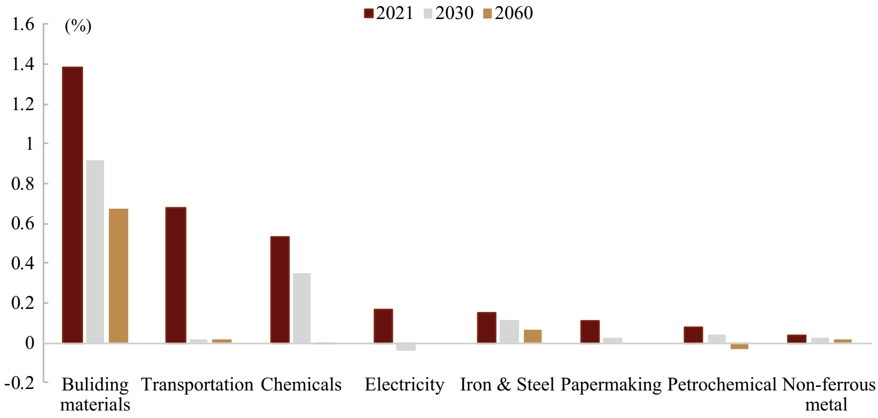


Fig. 3.11 Green premiums in various industries. *Source* CEADS, Wind Info, CICC Research

too much about the fact that innovation incentives are weakened under uncertain carbon prices.

As shown in Fig. 3.11, the green premium ratios of the low-emission, high-premium transportation and chemical industries in 2021 are 68% and 53% respectively, indicating that carbon neutrality technologies in these two industries have a long way to go before reaching maturity, and there is an urgent need to promote related research and development and technological progress. In the meantime, the combined emissions of these two industries account for only 10% of total emissions. This means that even if restrictions on total emissions are imposed on these two industries, their contribution to overall emissions reduction may not be as obvious as that of the power and steel industries. Meanwhile, highly volatile carbon prices in the carbon market may not be conducive to the technological progress in the transportation and chemical industries. Therefore, weighing the pros and cons, it may be more suitable to adopt the carbon tax-based carbon pricing mechanism for the transportation and chemical industries with low emissions and high green premiums. The construction material industry's emissions account for 12.6% of the total, ranking No. 3 among the 8 industries and roughly near the average level of 11%. In the meantime, the industry's green premium is as high as 138%, much higher than the 68% of the transportation industry, which ranks No. 2. Relatively speaking, the construction material industry needs more incentives for innovation and technological progress. Therefore, the carbon tax-based carbon pricing mechanism may also be suitable for the construction material industry.

As for the nonferrous metals, petrochemicals, and papermaking industries, their emissions account for 0.68%, 1.46%, and 0.26% of the total, respectively, and the green premiums in these three industries are 3.7%, 7.4%, and 10.9%. As their green premiums and share of emissions are relatively low, it seems that either pricing mechanism can work in the three industries. However, considering the transaction cost of the emission market is much higher than the carbon tax, from the perspective of reducing the unnecessary burden of emission reduction on companies, the carbon tax is an ideal choice.

3.2.3 Establishing a Carbon Market Trading Mechanism with Auctions and Futures at the Core

The analysis based on green premium shows that the power and steel industries are more suitable for adopting the carbon market-based carbon pricing mechanism, which together account for 62% of total emissions. Therefore, although the carbon market is not suitable to be the sole pricing mechanism, it is indeed the most important carbon pricing mechanism. To deal with issues like price uncertainty and insufficient innovation incentives, we recommend building an carbon market trading mechanism with "auction + carbon futures", implementing an auction-based mechanism in the allowances allocation and introduce options, futures and other derivatives in trading procedure.

3.2.3.1 Allocation of Emission Allowances: We Should Gradually Increase the Proportion of Paid Allocation via Auctions

According to the Coase Theorem, in a market mechanism with transaction costs, the initial allocation of property rights is directly related to the efficiency of market transaction. Therefore, whether the allocation of carbon emission allowances is reasonable provides the basis for the effective operation of the entire carbon market. In theory, there are mainly two ways of allocating carbon emission allowances, namely, free allocation based on the grandfathering method and the benchmarking method, and paid allocation, mainly by auctions.

China released *Measures for the Management of Carbon Emission Permits Trading (trial)* on October 28, 2020 and proposed to "introduce paid allocation of emission allowances in due course and gradually increase the proportion of paid allocation". In the document officially released on December 31, 2020, the wording was changed to "free allocation would be the mainstay, and paid allocation can be introduced in a timely manner per relevant government requirements". Looking at the wording alone, it seems that in the officially released document, greater emphasis is placed on the free allocation-based approach.

At the same time, the US RGGI uses auctions to allocate allowances and EU ETS has mainly adopted the auction approach in its third stage, as paid allocation of emission allowances could help to promote fairness. As mentioned above, the carbon market is a pricing mechanism with relatively high transaction costs. If there is no public revenue from auctions, the government, as a representative of public interest, will pay more using public funds to support the operation of the carbon market. If there is no revenue from auctions to cover the costs, it would be unfair for the public.

More importantly, auctions can help improve pricing efficiency and promote innovation. Regardless of whether the grandfathering method or the benchmarking method is adopted to allocate emission allowances, free emission allowances mean the absence of a price discovery mechanism in the allocation of emission allowances. Participants in the trading of emission allowances would bear all risks in price discovery and volatility. For example, during 2009–2013 when the EU ETS mainly focused on free allocation, the problem of excessive free allocations often occurred due to the lack of price signals in free allocation, which at one time led to a sharp drop in carbon prices and affected market activity.

In terms of mitigating the carbon market's adverse impact on innovation, it is more important to establish a price stabilization mechanism based on auctions and support renewable energy investment and green R&D through revenues from auctions. For example, in the EU ETS, if the auction clearing price is lower than the reserve price, the auction is cancelled, and a new auction is held.[21] In the RGGI in the US, the upper and lower limits of auction clearing prices are set through two different mechanisms: cost containment reserve (CCR) and emissions containment reserve (ECR). When the auction clearing price exceeds the trigger price, regulators release the CCR allowances to make the auction clearing price the CCR trigger price. When all the CCR allowances specified by policies are released, CCR allowances are no longer be released even if the auction clearing price is higher than the CCR trigger price; when the auction clearing price is lower than the ECR trigger price, regulators withdraw part of the auction allowances to make the auction clearing price the ECR trigger price.[22]

3.2.3.2 Emission Allowances Trading: Introduction of Futures and Other Financial Derivatives Should Be Taken into Consideration

As mentioned above, due to the low supply elasticity of carbon emission permits, the relatively large volatility of carbon prices has become a significant problem in the carbon market. How to control excessive volatility in carbon prices has also become one of the core issues in the design of the trading mechanism. The *Measures for the Management of Carbon Emission Permits Trading* released on December 31, 2020 proposed that trading of carbon emission permits should be conducted through a national carbon emission permits trading system, and agreed transfer, one-way bidding or other methods that meet requirements could be adopted in the system; excessive speculative trading behavior should be prevented. Judging from the previous pilot projects in 8 provinces and municipalities in China, control on spot prices of transactions such as upper and lower limits on price fluctuations is the main way to prevent excessive fluctuations in carbon trading prices. Only the Shanghai Environment and Energy Exchange has launched forward contracts for carbon, but

[21] EUROPEAN COMMISSION, EU ETS Handbook, 2015.

[22] RGGI Inc, RGGI Model Rule, 2017.

trading of financial derivative products for carbon is not due to constraints from China's carbon market not yet reaching maturity.

In fact, setting price limits for the spot market is just a way of delaying the release of real price signals and it is not a truly effective price stabilization mechanism, nor is it an effective way to help relevant companies avoid the risk of price fluctuations. Looking at EU ETS as an example, the EU launched a carbon futures product linked to the European Union Allowance (EUA) in April 2005, and a EUA options product in October 2006. In March and May 2008, carbon futures and options products linked to Certified Emission Reduction (CER) were launched. In 2019, the trading volume of carbon financial derivatives on the European Energy Exchange reached 426mn tonnes, of which the trading volume of EUA futures was 167mn tonnes, while the trading volume of carbon emission allowances in the spot market was only 50mn tonnes.[23]

In fact, financial derivatives such as carbon futures may be more important price risk hedging methods for emitting companies, as carbon emission allowances are a kind of artificially created emission rights product, and there are relatively concentrated delivery deadlines for such products. For companies engaged in production activities, carbon emission allowances as an asset cannot be directly put into production. If held until expiry, they will incur economic costs or opportunity costs, which could put a burden on the liquidity of companies. If carbon futures are introduced, companies will be given a choice: They can choose to sell the carbon emission allowances held by them in the spot market and buy futures for carbon emission allowances. This not only helps them hedge against the risk of price fluctuations, but also helps to unleash the liquidity occupied by carbon emission allowances to support the development of companies. For investors, carbon futures and other financial derivatives with carbon emission allowances as the target have more attributes of financial products than carbon emission allowances in the spot market, which could help attract more financial institutions to trade in the carbon market, and is conducive to improving the liquidity and pricing efficiency of the entire carbon market.

3.3 What Carbon Market Can and Cannot Do: Regional Transfer of Pollutants Under Carbon Trading[24]

A unified carbon market can help reduce the distortions caused by externalities of carbon emissions and improve the overall welfare of the country. However, it may also cause some unexpected problems in absence of other complementary policies. The

[23] EEX Group, Annual Report 2019, 2020.

[24] This section is co-written by CICC Global Institute and Guojun He, Assistant Professor of the Hong Kong University of Science and Technology. Mr. He is appointed jointly at Division of Social Science, Division of Environment and Sustainability, and Department of Economics at the Hong Kong University of Science and Technology. In addition, he holds a concurrent appointment at Energy Policy Institute at the University of Chicago (EPIC) and serves as the research director of its China center (EPIC-China).

strong correlation between emissions of carbon dioxide and air pollutants will lead to changes in the environmental quality in different regions after the establishment of the national carbon market, and may affect the benefits brought by the establishment of the carbon market in two specific aspects.

First, from a national point of view, for the same pollutant, even if the correlation between carbon dioxide and air pollutant emissions is positive, the overall carbon emission reduction may actually lead to an increase in the ultimate volume of pollutant emissions due to the differences in the elasticity coefficients between carbon and pollutant emissions in different provinces.

Second, from a regional (inter-provincial) perspective, when the carbon emissions of a region increase or decrease, emissions of air pollutants in the region are likely to change simultaneously due to the positive correlation between pollutants and emissions. However, as a kind of greenhouse gas, carbon dioxide is completely different from traditional air pollutants. Specifically, the externality of greenhouse gases is global, and greenhouse gases affect the changes in temperature of the entire planet and thus the welfare of all of humanity. However, the externality of air pollutants is regional, and emissions of air pollutants in a region mainly affect the region alone (transboundary air pollution does exist but its externality will be greatly reduced with the increase of distance). Therefore, if a province substantially increases its carbon emissions through emission permits trading, air pollutants that move along with carbon emissions have a great impact on the province's environment.

For example, we estimated changes in sulfur dioxide emissions in each province based on the changes in carbon emissions and the correlation coefficient between carbon and sulfur dioxide emissions under a unified carbon trading market. If carbon intensity drops by 4.5%, not all regions see increasing sulfur dioxide emissions when carbon emissions in these regions increase. On the contrary, carbon emission permits trading could lead to a decrease in sulfur dioxide emissions in some regions. Regions such as Henan in central China and Sichuan and Yunnan in western China have lower marginal costs for emission reduction. By selling carbon emission permits, sulfur dioxide emissions could decline by more than 10,000 tonnes in all these regions. However, in the Beijing-Tianjin-Hebei region and coastal regions, we can generally observe an increase in sulfur dioxide emissions. Combined with the above figure, we can see that if carbon emissions increase by about 2% under this scenario, sulfur dioxide emissions are likely to increase by more than 10% nationwide. Under strict policy constraints (the 7.5% scenario), sulfur dioxide emissions in coastal regions of eastern China and regions of central China would be reduced substantially. However, in the Beijing-Tianjin-Hebei region and a few provinces in western China, sulfur dioxide emissions would still increase. In particular, it can be seen that regions with increasing sulfur dioxide emissions would be concentrated in some regions of northern China such as the Beijing-Tianjin-Hebei region, where environmental pollution is more serious at present. For regions in southern China with better environmental conditions, carbon market could further improve the local environment. The above results may have two implications.

First, the movement of carbon emissions may cause unexpected movement of pollution, which could lead to distortions in pollutant emissions. The carbon market optimizes the allocation of cross-industry and cross-regional carbon resources in a market-based way so as to allow industries with higher emission reduction costs to reduce emissions less and encourage those with lower emission reduction costs to reduce emissions more, hence reducing distortions in carbon emissions. Corresponding to the carbon market is the potential pollutants market. In the absence of a pollutants market, if carbon emissions and pollutant emissions are highly correlated, but as the cost of pollutant emission reduction is inconsistent with the cost of carbon dioxide emission reduction, it may cause industries with higher pollutant emission reduction costs to reduce emissions more, and those with lower pollutant emission reduction costs to reduce emissions less. A certain degree of pollutants emission distortion cannot be avoided. To solve such problems, it is necessary to correctly evaluate pollutants emission reduction cost, understand the substitutive and complementary relationships between pollutants and carbon emission reduction costs and between emission reduction costs of different pollutants, and use the appropriate methods to coordinate the relationship between the carbon market and the potential pollutants market.

Second, there may be lack of compatibility in incentives between the national unified carbon market and environmental policies. At the national level, due to the heterogeneity of the relationship between carbon emissions and pollutants in different regions, increasing (or decreasing) total carbon emissions in a national unified carbon market does not mean that the total volume of pollutants in the country will increase (or decrease). At the regional level, greenhouse gas emissions are a global problem, while pollutant emissions are a local problem. The central government and local governments may have different preferences and requirements for regulatory policies on these two types of problems, resulting in different regulatory motives. As pollutants and carbon emissions are highly correlated, existing regional environmental policies may affect the carbon market in the form of "cross subsidies", making carbon emissions subject to both the regulation of the carbon market and the impact of pollutant regulation. Based on the above results, a national carbon market may not be able to promote emissions reduction for all pollutants. More importantly, a national carbon market may exacerbate the air pollution problem in some regions of northern China such as the Beijing-Tianjin-Hebei region, which may be incompatible with many existing environmental protection goals. Therefore, it is necessary to clarify the relationship between various environmental protection policies and climate governance policies to avoid the emergence of many repetitive and contradictory policies, which would not only increase the various transaction costs of companies and administrative costs of the government, but also negatively affect efficiency and welfare levels.

In addition to the contradiction between environmental policies and a unified carbon market, such problems may be widespread in industries and policies related to carbon emissions. For example, in view of power industry emission reduction's key role in carbon emission reduction, achieving coordinated advancement of the carbon market and the electricity price reform may require prudent design of price mechanisms and the consideration of additional targeted regulatory policies. Therefore, while promoting carbon emission reduction through the carbon market, it is also

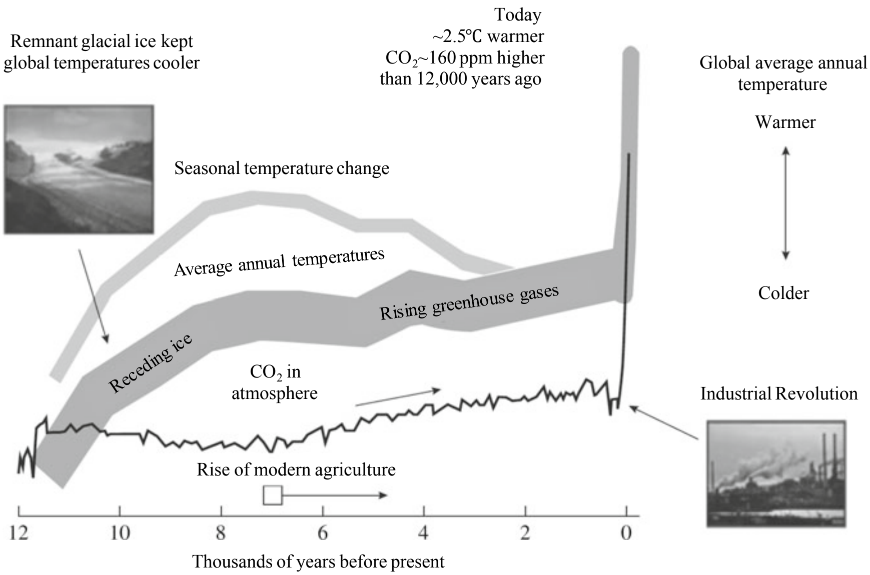


Fig. 3.12 The process of temperature evolution during the Holocene epoch.[25] *Source* Samantha Bova, Seasonal origin of the thermal maxima at the Holocene and the last interglacial, Nature, 2021, CICC Global Institute

necessary to jointly analyze the effects of interaction between related markets as soon as possible, assess the true cost of various regulations, and avoid the externalities that are counterproductive to the regulation of a specific market.

3.3.1 Social Governance: A Policy Instrument to Lower Green Premium in Addition to Carbon Pricing

Three Types of Carbon Neutrality Policies and Two Types of Carbon Emissions

Based on the discussion of carbon pricing from the perspective of green premium, we have observed that technological progress is important or even decisive for carbon neutrality. However, according to the Holocene time series data (see Fig. 3.12), the rate of increase in carbon dioxide concentration in the air has accelerated because of the Industrial Revolution, but such an upward trend began when human civilization became increasingly sophisticated starting 6,000–7,000 years ago. In other words, technology has been an important accelerator for the upward trend of greenhouse gas concentration for thousands of years, but the root cause lies in the economic activities

[25] Samantha Bova, Seasonal origin of the thermal maxima at the Holocene and the last interglacial, Nature (2021).

of humankind. Looking at the road to carbon neutrality from this perspective, it is important to promote progress in clean technology, but it is also necessary to strengthen social governance that regulates human economic activities.

In order to regulate human economic activities, we can take reference from the classification method for environmental protection policies and classify carbon neutrality policy instruments into three types: mandatory policies, price-based policies and advocacy policies. Price-based polices are considered the most important type of carbon neutrality policy. Mandatory policies mainly refer to policies that rely on the government's compulsory orders or laws and regulations. Such policies include institutionalized formulation and implementation of emission standards and routine administrative intervention for emission behavior. Production shutdown or curtailment and the license plate policy that restricts the use of cars also belong to the category of mandatory policies. Advocacy policies influence human emission behavior via methods such as information disclosures and advocacy targeting public opinions. Such policies are usually not mandatory and offer no material incentives, and they promote carbon neutrality by raising people's awareness of emission reduction.

Viewing from lowering the green premium, the differences between these three types of carbon neutrality policies are not clear-cut. For example, carbon pricing mechanisms, whether carbon tax or carbon market, must be built on the MRV system based on mandatory policies. If there is no compulsory force to promote the actual implementation of relevant systems and effectively deter violations, the design of carbon pricing mechanisms would be in vain. The same applies to the field of green finance. How to identify and confirm the authenticity of green projects also needs to be established based on a series of rules and regulations. In an economy where the habit of paying for carbon emissions has not been developed, if we want the general public to accept the carbon pricing mechanism as soon as possible and reduce frictions in the operation of the carbon pricing mechanism as much as possible, it would be necessary to step up efforts to advocate and raise the awareness of carbon neutrality among the general public. According to OECD research (2020), 16% of revenues from auctions in the carbon market were invested in carbon neutrality-related education, training and other fields.[26] Therefore, social governance policies such as mandatory and advocacy policies are also important tools to help to lower the green premium.

Moreover, mandatory and advocacy policies have their own policy implications from the perspective of social governance. Here, we need to distinguish between two types of carbon emission behavior, namely reasonable carbon emissions and unreasonable carbon emissions. So-called reasonable carbon emissions refer to carbon emissions that are necessary for meeting the needs of the survival and development of human society. Without such emissions, human society would suffer relatively serious welfare losses. For example, Japan launched large-scale energy conservation campaigns after the nuclear accident at the Fukushima nuclear power plant, but research indicates that this led to an increase in mortality rate during summer, largely

[26] OECD, *The use of revenues from carbon pricing*, 2019.

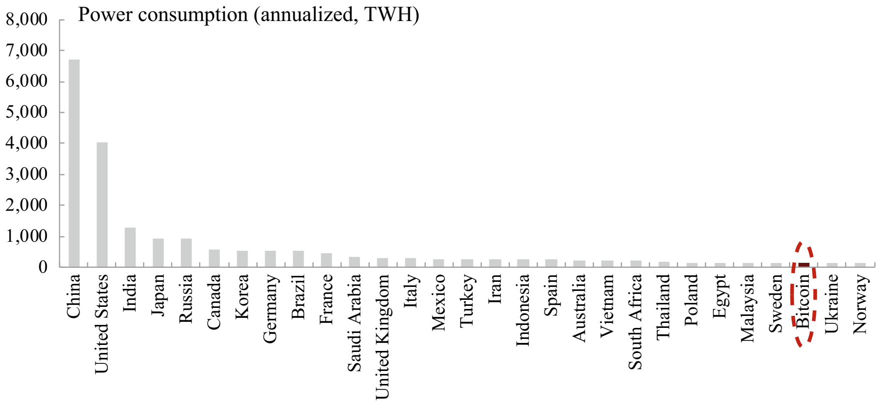


Fig. 3.13 Annualized power consumption by bitcoin mining ranks 27th among economies in the world.[28] *Source* US Energy Information Administration, University of Cambridge, CICC Global Institute

because energy conservation reduced the use of air-conditioning in high-temperature weather.[27] In this example, if sufficient energy supply was to be provided despite increasing carbon emissions and thereby lower the mortality rate of humans, such carbon emissions can be considered as reasonable carbon emissions. It is more appropriate to use price-based policies to reduce green premiums and promote carbon neutrality for reasonable emission behavior.

So-called unreasonable carbon emissions refer to emissions caused by economic activities that are not necessary for human survival and development. Waste is the most typical type of unreasonable carbon emissions. The waste discussed here includes waste in the physical world such as food waste, which has raised widespread concerns, and waste of financial resources as seen in bitcoin mining (Fig. 3.13). The wasteful behavior in the financial sector could generate large returns, and price-based policies may not be effective enough to curb such behavior; the wasteful behavior in the residential sector involves a wide range of various aspects and pushing price-based policies too hard may cause greater social friction if awareness of carbon neutrality is weak. Therefore, for such unreasonable carbon emissions, it may be more suitable to adopt mandatory or advocacy social governance policies.

[27] Guojun He, Takano Tanaka (2021), *Energy Saving May Kill: Evidence from the Fukushima Nuclear Accident*, working paper.

[28] If the annualized electric power consumption by bitcoin mining is regarded as the electric power consumption of an economy, annualized power consumption by bitcoin mining would rank 27th in the world. Power consumption of economies is based on data in 2018, and power consumption by bitcoin is the annualized power consumption data as of February 2021.

3.3.2 Mandatory Policies Can Be Used to Regulate Waste of Financial Resources as Seen in Bitcoin Mining

Due to the low administrative costs of implementation, mandatory policies are the earliest type of environmental protection policies from a global perspective, and also the most common policy instrument for environmental protection in China. Examples of such policies include restrictions on purchasing and driving cars and restrictions on the use of electricity to meet requirements on emissions. However, mandatory policies have also exposed some problems in the long-term process of implementation. Due to information asymmetry, mandatory policies may produce unexpected effects. For example, the use of chlorofluorocarbons (CFCs) has been banned in order to protect the ozone layer, which has promoted the use of hydrochlorofluorocarbons (HCFCs), and this ultimately "unexpectedly" exacerbated the problem of global warming.[29] Meanwhile, mandatory policies also usually present problems such as lack of openness in the decision-making process, complicated approval process, and overly rigid enforcement process. If policies with such characteristics are applied to reasonable carbon emissions, it may cause additional transaction costs or opportunity costs.

It should be noted that some of the above-mentioned problems are mainly due to the decision-making mechanism of mandatory policies, and this does not mean that mandatory policies are undesirable. In fact, if more opinions from all relevant parties in the decision-making process can be solicited and mandatory policies can be implemented through a rule-based system rather than through discretionary administrative methods, the effect of such policies may be greatly improved. More importantly, although such policies have been criticized for their rigidity and lack of flexibility, they may be an ideal method to deal with unreasonable carbon emission activities such as bitcoin mining.

We assume that bitcoin will become a real currency, and that more and more people will rely on bitcoin mining instead of producing general goods and services to make money. Will this be a waste of social resources?[30] In fact, bitcoin mining consumes about 130 gigawatt-hours of electricity annually. Given about 0.529kg of carbon dioxide is produced per kilowatt-hour of electricity consumption in China, annual electricity consumption by bitcoin could generate 68.77mn tonnes of carbon dioxide emissions. From the perspective of currency creation, the 68.77mn tonnes of carbon emissions do not need to be generated. In the meantime, bitcoin mining could generate attractive profits, and ordinary price-based policy instruments may not be effective in preventing such wasteful behavior. Therefore, we could consider prohibiting such activities through mandatory policies for unreasonable carbon emissions with financial characteristics such as bitcoin mining.

From the perspective of lowering green premium, mandatory policies also have great significance for the sustainable reduction in green premium in the future. The

---

[29] Miranda Schreurs: *Perspectives on Environmental Governance*, Research of Environmental Sciences, Vol.19, Supplement, 2006.

[30] PENG Wensheng: *Monetary implications of the financial technology*, September 2017.

large-scale use of zero-emission technologies may cause a decline in the demand for emission-generating technologies. For example, large-scale launches of clean-energy power generation projects may affect the demand for thermal power generation and lower the price of fossil energy and the production cost of emission-generating technologies.[31] This may lead to a rebound in green premium, which could reduce the entire society's motivation to move towards carbon neutrality. Therefore, it is necessary to define the production supported by emission-generating technologies as unreasonable carbon emissions through administrative orders when it is economically feasible to use zero-emission technologies on a large scale, and to prohibit the re-expansion of the production capacity supported by emission-generating technologies through administrative orders.

3.3.3 Advocacy Policies as Necessary Move to Control Waste of Resources in the Real Economy

In the field of environmental protection, the importance of advocacy policies has been increasingly emphasized globally in recent years. The main reason for this is that policymakers are increasingly aware that whether it is environmental protection in a broad sense or carbon emissions in a narrow sense, it is a problem that involves the entire human race, and it is not only related to the contemporary era but also involves the welfare of humans in the future. It is necessary to raise awareness on environmental protection and emission reduction among the general public. In terms of the nature of means, advocacy policies are less compulsory and binding than mandatory policies, and their effectiveness is generally considered to be lower than material incentive effects of price-based policies. Nonetheless, this does not mean that advocacy policies are ineffective. For example, studies have shown that the automatic disclosure of PM10 concentration data has substantially increased online searches for face masks and air purifiers.[32] To a certain extent, this reflects environmental protection information disclosure's effects on people's behavior by improving the level of welfare as measured by people's health. More importantly, advocacy policies could help raise the awareness on environmental protection among the general public. This means that subtle influence for a long period of time could promote gradual low-carbon evolution of the utility function among the general public, which improves

[31] If demand for fossil energy continues to shrink, the decline in prices will also cause the industry to spontaneously enter supply-side contraction, which is specifically reflected in the reduction of investment and the degradation of mining technologies. Therefore, in the case of large-scale promotion of zero-emission technologies, upward and downward pressure on prices of fossil energy will both appear. It may be difficult to judge which will become dominant, but in the face of the risk of reversal of downward trend in green premium, it is still necessary to take mandatory prohibitive measures at some stages.

[32] Michael Greenstone, Guojun He, Ruixue Jia, Tong Liu, 2020. Can Technology Solve the Principal-Agent Problem? Evidence from China's War on Air Pollution, Working Papers 2020–87, Becker Friedman Institute for Research in Economics.

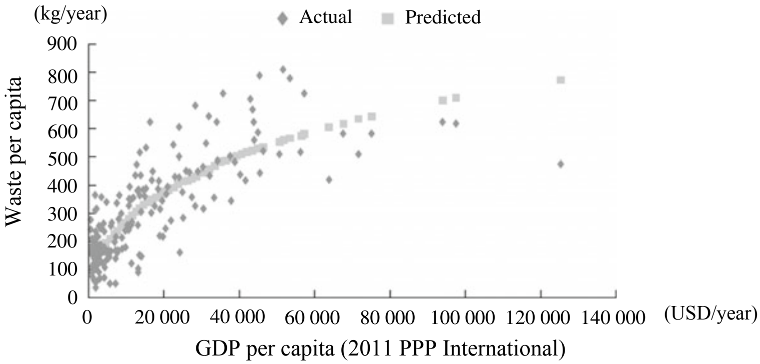


Fig. 3.14 GDP per capita and per capita solid waste generation volume.[34] *Source* World Bank, CICC Global Institute

the acceptance of price-based policies and mandatory policies by the general public, and lays the foundation for promoting price-based policies and mandatory policies.

For China, raising awareness on anti-waste practices among the general public may be an important direction for the use of advocacy policies at present. In fact, waste of resources does not only exist in bitcoin mining in the financial sector, but is even more common in the real economy. If solid waste is used as a measure of waste of resources,[33] the global volume of solid waste generated in 2016 was as high as 2.01bn tonnes, and the solid waste spread almost all over the world. Such a broad group of waste is very different from a small group of people's wasteful behavior such as bitcoin mining. China has a large population and the country's overall waste generation volume is large. However, as GDP per capita in China is not high, the current per capita solid waste generation volume is not at a high level in the country. On the one hand, these characteristics and facts mean that China should adopt policies to control waste at the current stage. This is because the country's GDP per capita is likely to double in the next 15 years as China gradually grows from an upper middle-income country to a high-income country, implying that China's per capita solid waste generation volume and total solid waste generation volume are still likely to grow rapidly (Fig. 3.14).

On the other hand, this also means that it may not be suitable to deal with the problem of waste among residents mainly through compulsory policies or incentive price-based policies at the current stage. Looking at waste sorting as an example, compared to developed countries, China's per capita solid waste generation volume is still at a relatively low level. In the early stage of controlling wasteful and unreasonable carbon emissions by residents, if mandatory or price-based policies are directly

[33] Strictly speaking, solid waste is not equal to waste of resources, but generally speaking, their changes are mostly in the same direction. Therefore, the waste of resources can be roughly observed by observing the amount of solid waste generated.

[34] World Bank: *What a Waste 2.0 A Global Snapshot of Solid Waste Management to 2050*, published in 2018.

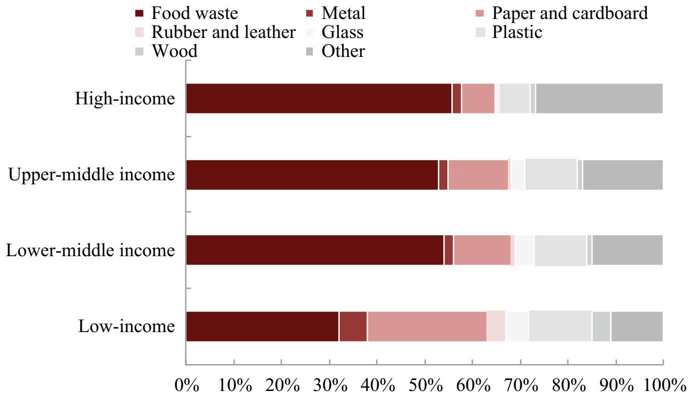


Fig. 3.15 Composition of solid waste in economies with different income levels.[35] *Source* World Bank, CICC Global Institute

used to intervene, either relevant mandatory or price-based policies may become mere formalities, or such policies may easily increase the friction cost of social governance and cannot be sustained for various reasons (e.g., it may be difficult to implement a new policy among the general public, and residents' awareness of environmental protection needs to be improved further).

Therefore, currently, we can consider using advocacy policies with the main goal of raising residents' awareness of low carbon emissions as the main methods of low-carbon governance for residents, such as waste sorting. After the awareness of emission reduction gradually increases among the general public, we could then consider converting relevant advocacy policies into institutionalized, mandatory, or price-based policies. In the meantime, according to World Bank statistics, when an economy grows from an upper high-income economy into a high-income economy, there will be two important structural changes in its waste generation. First, the proportion of food waste will drop sharply, but it will remain the largest source of waste. Second, the proportion of paper and cardboard waste will likely double and become the second largest source of waste (Fig. 3.15). This means that China must step up efforts to advocate the collection of sorted food waste and paper and cardboard waste in the process of controlling waste as soon as possible, and gradually promote institutionalized or price-based waste sorting, collection and treatment.

[35] World Bank: *What a Waste 2.0 A Global Snapshot of Solid Waste Management to 2050*, published in 2018.

Chapter 4
Green Finance: Clarifying Functions and Capacity

Abstract Unlike traditional finance, green finance (e.g. green loans or green bonds) aims to address the current inadequate levels of investment and financing available for green development as a result of "market failure". Finance usually follows and serves the real economy in an effective market. However, when the market is ineffective in allocating resources to green development, green finance should enhance its guiding role in the real economy in order to reduce the cost of green investment and financing, improve the accessibility of green funds and even meet the demand for green investment and financing by establishing new trading markets. China has made considerable progress in green finance with a decent market for financial products such as green credits and bonds. However, several obstacles need to be overcome to realize carbon neutrality, such as inadequate green investment and financing, lack of unified standards for green finance and the absence of mandatory requirements on information disclosure. To realize carbon neutrality, we estimate China needs to invest Rmb139trn before 2060 and Rmb22trn before 2030. It will be a significant challenge for China's green finance system to meet such enormous demand for green investment and financing. To better promote green development, China should establish a unified standard for green finance, improve mechanisms for green information disclosure, strengthen policy incentives for internalizing externalities, develop a more diversified green financial market, enhance education and awareness about green investment and include environmental risks into regulatory policy considerations. These actions should help turn the challenges of the next 4 decades into unprecedented opportunities for green development.

4.1 Green Finance: Serving or Guiding the Real Economy?

Internationally, green finance is generally defined as financial activities related to sustainable development. Most countries and international organizations define green finance based on the ultimate goals of financial activities, that is, a financial activity can be regarded as green if its ultimate goal is related to real-economy activities on sustainable development. However, these definitions might not be adequate to

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_4

fully understand the significance of green finance. We believe two issues need to be discussed before we dive into deeper analysis.

First, what is the ultimate goal of green finance?

For the real economy, the core goal of green finance is realizing carbon neutrality, and the essence of achieving this target is to address carbon emissions that impact the world beyond the scope of time and space. We previously introduced the concept of green premium, an essential measure to realize carbon neutrality. Both accomplishing carbon neutrality and reducing the green premium are the goals of the real economy; however, coordination and support from financial activities are also indispensable to achieve these goals.

Second, how to understand the relationship between finance and the real economy?

In addition to the serving function, finance also guides the resource allocation of real economy. When finance mainly plays the role of serving the real economy, the latter takes the dominant position and financial activities should act in accordance with its development. However, finance is also an important means of resource allocation, and can guide the development of the real economy.

Combining the previous two questions, green finance can therefore be divided into service-oriented and guidance-oriented green finance. Both aim to reduce the green premium, albeit through different channels.

- Service-oriented green finance: In this type of finance, real economy reform is the fundamental source of green premium reduction, and finance plays a supplementary role, providing financial services based on the demand of low-carbon transformation of the real economy. In this case, policy fine-tuning, technological advances and changes in social governance mechanisms all center on real-economy sectors. Actions to reduce carbon emissions in real-economy sectors would lower the green premium, and raise the relative cost of industries that produce high emissions or the relative returns of more environmentally friendly industries. Reflected in the financial markets, such changes in relative prices would lead to changes in the financing demand and prices of the low-carbon economy. Based on the principle of profit maximization, the financial sector will meet the financing demand of the real economy and provide corresponding financial services. The financial sector in this case mainly facilitates the green transformation of the real economy, indirectly helping reduce the green premium rather than directly.
- Guidance-oriented green finance: Financial activities directly lower the green premium, and guide the low-carbon transformation of the real economy. In this case, the financial sector can also be the direct driver of green premium reduction. As important productive inputs, different ways of funding allocation can directly affect resource distribution of the real economy. Even without reforms in the real economy, the financial sector can fine-tune the relative production cost of high-carbon and low-carbon industries and hence reduce the green premium, if the financial sector could effectively distinguish emission-increasing financing activities from emission-decreasing financing activities and reduce the financing cost of the latter or increase the expenses of the former accordingly. During the

process, reform of the financial sector will be the direct driver of lowering the green premium, and resource allocation of the real economy will follow the changes of the financial sector.

The development of green finance requires close collaboration between service-oriented and guidance-oriented green finance, suggesting an indispensable position for both. As we previously discussed, carbon emission is a complex externality issue influencing the whole world across different time and space, and it is much more difficult to address than any other externality issues. All means to address the problem of carbon emissions such as establishing a carbon trading market, imposing a carbon tax, promoting technological advances and implementing non-market-oriented measures, are very complicated undertakings with various uncertainties. Therefore, China still needs to promote guidance-oriented green finance and regard it as an essential strategy to reduce the green premium.

4.2 Green Finance in China

China has made preliminary progress in establishing infrastructure for green finance. In 2014, the People's Bank of China and UNEP Inquiry jointly established the Green Finance Task Force, and proposed 14 recommendations for developing a green finance system. Following that, a number of documents have been released to help establish China's green finance system, including the "Green Bond Endorsed Projects Catalogue", "Guiding Opinions on Building a Green Financial System" and "Notice on the Establishment of a Special Statistical System for Green Loans" (Fig. 4.1).

- **Firstly, preliminary classification standards for green industries, green loans and green bonds are in place**. The National Development and Reform Commission issued the "Green Industry Directory Guidance" in March 2019, which provides a comprehensive classification of green industries. Based on the Guidance, various financing tools have established different classification standards, among which the standards of green loans and green bonds are relatively mature. China in 2013 released the "Green Credit Statistics System" that clearly defines what projects are eligible for green credit loans. It marked one of the first efforts to establish a green loan system in emerging markets. For green bonds, the definition of green industries or projects is mainly based on guidance or catalogues released by corresponding regulators. The guidance on green bond issuance released by the National Development and Reform Commission in 2015 stipulated that proceeds raised from green corporate bonds should be invested in projects related to green, recycling and low-carbon development. Other types of green bond projects mainly refer to those included in the green bond endorsed projects catalogue released in 2015.
- **Secondly, evaluation systems for investment and financing tools have gradually been established**. Comparatively speaking, the evaluation system for green

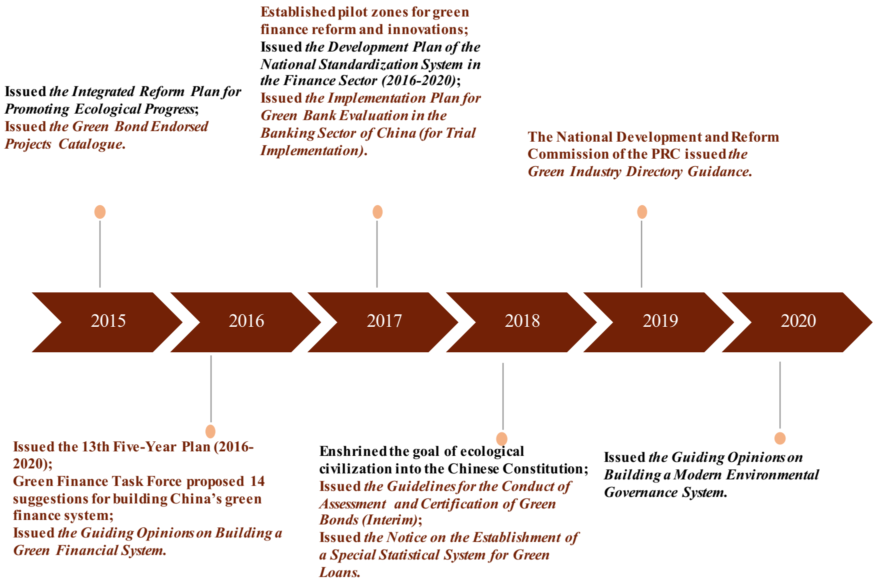


Fig. 4.1 Major policies in China's green finance reforms. *Source* Climate Policy Initiative, CICC Research

credit loans is the most comprehensive one in China. In 2014, the self-evaluation system for green credit was set up for banks, evaluating the extent of green credit development from a qualitative perspective, as well as setting the balance of loans for energy-saving and environmentally-friendly projects, "Two Highs and One Overcapacity" industry, and CO_2 emission reduction as key indicators to assess performance from a quantitative perspective. In 2018, the People's Bank of China increased the frequency of performance evaluations for green credit loans, introducing the central bank as an external evaluator and including the results of the evaluations in its macro prudential assessment. In addition, a rating system for ESG investment has basically been formulated. China Securities Index Company Limited in December 2020 released the CSI ESG rating method that thoroughly considers the industry characteristics and information quality of listed companies, comprising 3 components (i.e. environmental, social and corporate governance), 14 themes, 22 units and over 100 underlying indicators.

- **Thirdly, development of legal systems and regulatory rules has begun**. Ecological civilization was included into China's constitution in 2018 with legal status of green finance being recognized indirectly. From the regulatory side, the People's Bank of China has launched the Green Finance Committee to regulate the development of green finance. Meanwhile, various regulatory measures have been adopted for different financing tools. For example, financial institutions that issue green loans need to report relevant data to financial regulators. On information disclosure, China has started to mandate listed companies to disclose information about major pollutants from production, major processing facilities for these pollutants and their capacity in recent years. Moreover, companies listed on the ChiNext are required to disclose information about social responsibility.

Amid the improving infrastructure, China's green finance market has seen considerable development, mainly in indirect financing. Data from the People's Bank of China shows that the amount of domestic green-financing totaled about Rmb13trn by the end of 2020, including Rmb12trn of green credit loans and Rmb870bn of green bonds. Meanwhile, the green equity market in China remains relatively small and PE/VC equity investment, green IPOs and follow-on equity offerings by green enterprises have just started. Green equity investment in China averaged Rmb42.4bn[1] over 2018–2019, well below the Rmb550bn for annual incremental green loans and green bonds.[2] However, growth of green financing has decelerated in recent years. The balance of green loans at banks rose at a CAGR of 12.3% between end-June 2013 and end-June 2020 from Rmb4.90trn to Rmb11.01trn. That said, growth of green loan balance (3.9% at end-1H20) was slower than overall loan balance growth in recent years (13% at end-1H20).

Green bonds currently do not have advantages in pricing and their financing terms are generally short. Based on the green bonds issued since 2020, we note that about 80% of green bond issuers had a positive interest rate spread compared with overall bond yields, especially for bonds with medium/low ratings. For example, over 90% of the AA+ rated green bonds had a positive interest rate spread.

From a term perspective, 1–3Y green bonds account for 43% of outstanding green bonds, while the 3–5Y and 5–10Y green bonds account for 37% and 11%, respectively. Generally speaking, the terms of green bonds remain relatively short, and thus cannot provide financing for the long-term investment required for developing green technologies and clean energies, or promoting carbon offset projects such as afforestation. Due to the lack of long-term funding, domestic PE/VC funds usually last for about 5–7 years,[3] but it may take about 7–10 years for green-tech companies to qualify for an IPO. As a result, domestic equity investment institutions are less interested in green-tech companies.

From an industry perspective, transportation and energy sectors account for a large portion of green financing. As of end-2019, green transportation made up 44% of total green loans, while renewable energy and clean energy represented 24%. By the end of 3Q20, transportation, warehousing and delivery accounted for 30% of green loans, while the power, heat, gas and water production and supply industries took up another 29%. The proportion of other sectors climbed from 24% in end-2018 to 41% in 3Q20, implying a diversified trend in sector distribution of green loans. In green bond financing, the financial sector has long accounted for the largest proportion,

---

[1] Based on data from International Institute of Green Finance at Central University of Finance and Economics and Asset Management Association of China.

[2] Estimated based on the balance of green loans at banks and Wind Info data.

[3] Based on data from An, Guojun. For Lucid Waters and Green Mountains- A Journey on Financial Innovation. 2020.

and that of green bonds issued by the industrial and utility sectors have increased significantly in recent years, accounting for 45%, 30% and 18% of green bond issuers in 2020 respectively. Other sectors represented less than 5%, mainly concentrated in heavy-asset industries that have abundant resources of financing.

4.3 How Much Investment is Needed to Achieve Carbon Neutrality?

Achieving peak carbon emissions and carbon neutrality are the two important targets for green development in China, and have been included in the 14th Five-Year Plan and the Long-Range Objectives through the Year 2035, which implies a substantial demand for funding. Proper assessment of the funding demand and its structure should allow the financial system to better serve and guide China's low-carbon transformation. Our bottom-up analysis shows that China's total green investment demand should reach about Rmb139trn[4] to achieve carbon neutrality, including Rmb22trn over 2021–2030 and Rmb117trn over 2031–2060.

4.3.1 Bottom-up Analysis of China's Demand for Green Investment

It is a complicated task to estimate the amount of investment needed for carbon emission reduction for financial institutions, but from the perspective of the green premium, the investment needed is simply the amount of funds required to replace traditional technologies and equipment causing high carbon emissions with those that reduce carbon emissions. As shown in Fig. 4.2, we divide technologies and equipment into four categories, namely existing high-carbon technologies and equipment, existing low-carbon technologies and equipment, older technologies and equipment that need to be upgraded, and innovative low-carbon technologies and equipment. To reach peak carbon emissions and move toward carbon neutrality, we have to reduce the production capacity that relies only on high-carbon technologies and equipment (meaning no further investment), and increase capacity of the other three technologies and equipment. We can roughly estimate the amount of investment for each category of technologies and equipment at different times based on the changes in capacity and the investment/capacity ratio under anticipated progress of emissions reduction, and then add up to calculate the aggregate green investment demand.

To fully estimate the amount of investment, we select seven sectors with the highest carbon emissions in China and calculate the green investment demand from

[4] Based on prices in 2020.

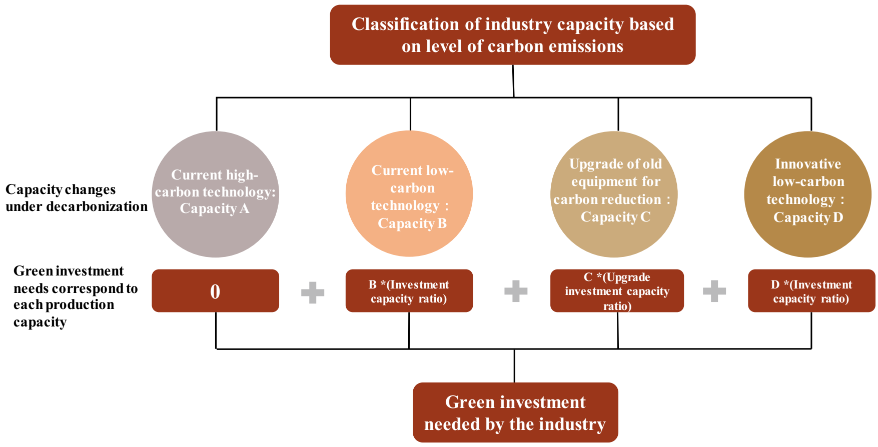


Fig. 4.2 Methods for estimating green investment. *Source* CICC Global Institute

them. Based on data from China Emission Accounts and Datasets, the seven sectors[5] accounted for over 85% of China's total carbon emissions in 2017. They are also the major sectors with fixed asset expansion.

4.3.2 Aggregate Investment Demand and Structural Features

4.3.2.1 Annualized Green Investment Accounts for about 2% of GDP

Considering the investment demand of major sectors, we estimate that China's green investment demand needs to total about Rmb139trn[6] to achieve carbon neutrality with annual green investment demand accounting for about 2%[7] of GDP on average.

Specifically, we estimate China's annual green investment demand will hit Rmb2.2trn over 2021–2030 to reach peak carbon emissions, and reach Rmb3.9trn over 2031–2060 to achieve carbon neutrality. Over 2021–2060, China's annual green investment demand needs to be Rmb3.5trn to achieve carbon neutrality (Fig. 4.3). According to GFMA's (2020) assessment, global green investment demand will need to total US$121.7trn[8] to reach carbon neutrality, and China's green investment based on our calculation will comprise 17%[9] of the global demand.

[5] Compared with the eight sectors mentioned in previous chapters, we included airlines into the transportation sector and replaced papermaking with agriculture.

[6] Based on 2020 prices.

[7] Actual ratio fluctuates with macroeconomic variables such as GDP.

[8] GFMA: Climate Finance Markets and the Real Economy, 2020.12.

[9] Based on USD/RMB exchange rate at 1:6.7.

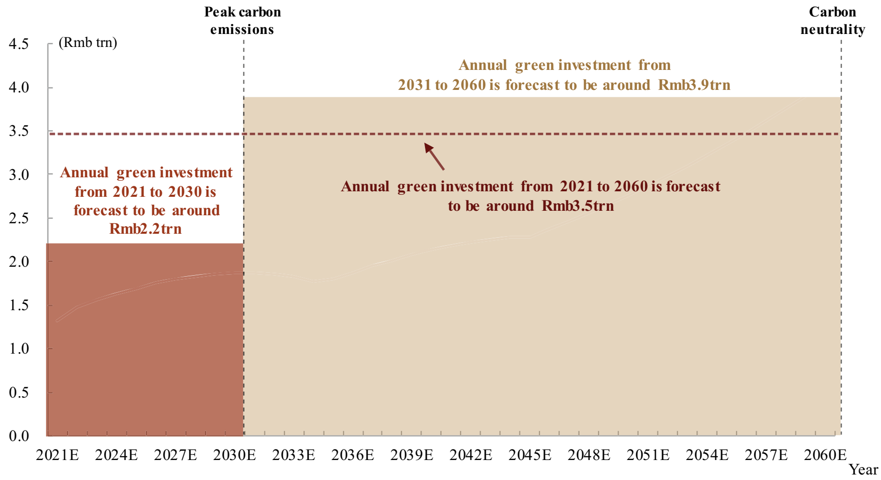


Fig. 4.3 Estimated green investment for China (based on 2020 prices). *Source* CICC Global Institute, CICC Research

4.3.2.2 Investment is Most Needed for Power Sector

To accomplish carbon neutrality, green investment is most needed for the power sector, which requires investment of Rmb67.4trn, followed by Rmb37.4trn for the transportation sector and Rmb22.3trn for the construction sector (Fig. 4.4). The need for investment in the power sector mainly comes from the spending on clean power-generation equipment, including Rmb16.2trn for solar power equipment and

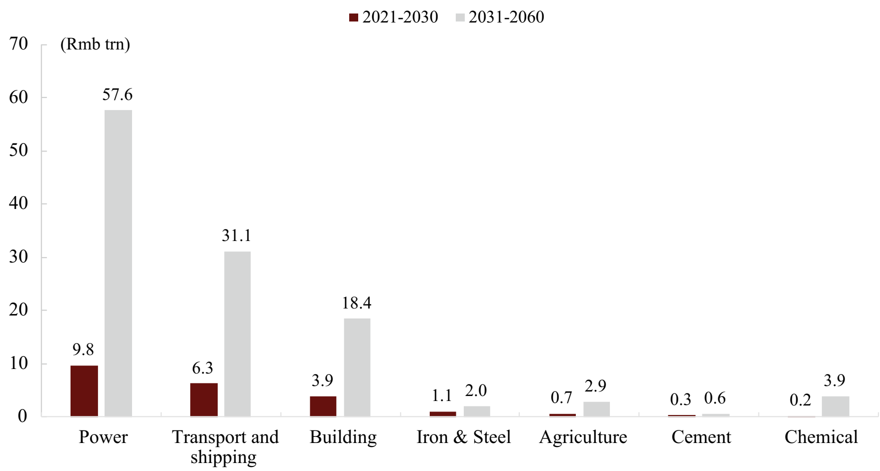


Fig. 4.4 Estimated green investment needed for different sectors to accomplish carbon-neutrality targets (based on 2020 prices). *Source* CICC Global Institute, CICC Research

Rmb14.3trn for wind power equipment. The need for investment is also high in the transportation sector. First, we expect China's electric vehicle output to grow significantly driven by the replacement of traditional fuel vehicles, and this would increase investment in new energy vehicles and related energy production. Second, we also foresee high investment in the low-carbon transformation in aircraft and vessels, as well as the development of new energy infrastructure. In terms of the building sector, the investment needs mainly result from the utilization of environmentally friendly and energy-saving technologies as well as low-carbon equipment. Meanwhile, the need for green investment is relatively low for the steel and cement sectors, and we expect their share of green investment to decline amid China's industrial restructuring.

4.3.2.3 Investment Demand is Likely to be Postponed for Sectors Facing Technological Hurdles in Emissions Reduction

Technological difficulty for emission reduction varies for different sectors. While the technologies are relatively mature for electric vehicles and EV chargers, it remains costly or not feasible for hydrogen-powered aircraft or carbon-capture technologies in cement production.

Variations in technological difficulty of emission reduction may lessen the incentive for emission-reduction investment in the early stages, thus increasing the risk of lagged investment accumulation. Table 4.1 shows the relative proportion of green investment for different sectors in 2021–2030 and 2031–2060. For sectors with greater technological difficulty in reducing carbon emissions, the relative proportion of green investment is lower for 2021–2030 and their investment demand is pushed to a later stage. This shows that select sectors anticipate technological advances that take place after reaching peak carbon emissions will lower technological difficulty for emissions reduction. However, a significant delay in investments may exacerbate the shortage of green investment and financing.

4.4 New Targets Bring in New Challenges. What Are the Weaknesses in China's Green Finance?

4.4.1 Mismatch Between Supply and Demand in Green Investment

4.4.1.1 Shortfall in Green Investment and Financing with Even Wider Gap After 2030

China is facing a sharp shortfall in green investment and financing, and the gap may widen after 2030. While the gap between green investment supply and demand

Table 4.1 Breakdown of green investment for different sectors

Industry		Source of green investment need	Investment need in 2021–2030 (Rmb bn)	Investment need in 2031–2060 (Rmb bn)
Power		Energy storage	100	13,700
		Grid investment	2,300	8,500
		Clean power generation	6,900	28,300
		Special facilities required for clean hydrogen production	0	3,100
Iron & Steel		H2 DRI-EAF	179	235
		DRI-EAF with CCUS	219	251
		Scrap-based EF with CCUS	377	1,216
Transport & Shipping	Light transport	Electric light duty vehicles manufacture (battery)	282	630
		Electric light duty vehicles manufacture (other parts)	38	50
		Electric charging infrastructure	1,849	22,288
	Heavy transport	Electric commercial vehicles manufacture (battery)	99	124
		Electric commercial vehicles manufacture (other parts)	7	8
		Clean fuel development	13	153
		Hydrogen refueling and other infrastructure		
	Aviation	Low carbon aircraft	70	1,442
			527	1,126

(continued)

Table 4.1 (continued)

Industry		Source of green investment need	Investment need in 2021–2030 (Rmb bn)	Investment need in 2031–2060 (Rmb bn)
		Hydrogen aircraft	0	503
		New energy	8	988
	Shipping	Low carbon transformation of ships	78	78
		New energy infrastructure	69	813
Cement		CCUS equipment	0	201
		Environmental protection technology transformation	14	54
Chemical		Fixed assets of new technology and clean energy	203	7,162
		Fixed assets of CCS installations	20	464
Agriculture		New equipment and technology R&D for no-till farming	25	293
		Equipment for manure management	216	660
		Artificial meat production	284	997
Building		Construction safety and built-in electrical appliances	3,922	18,439

Source CICC Global Institute, CICC Research

narrowed in 2017–2019, the shortfall was still high at about Rmb600bn in 2019 (Fig. 4.5). Considering the current supply of green investment, we estimate that the shortfall in green investment and financing may expand to Rmb5.4trn in 2021–2030 with an annual average amount of Rmb0.54trn. In addition, the shortage may worsen after 2030 due to the possibility of investment being postponed as mentioned earlier. Without policy intervention, we estimate that the shortfall in green investment and financing may rapidly increase to over Rmb1.3trn/year after 2031.

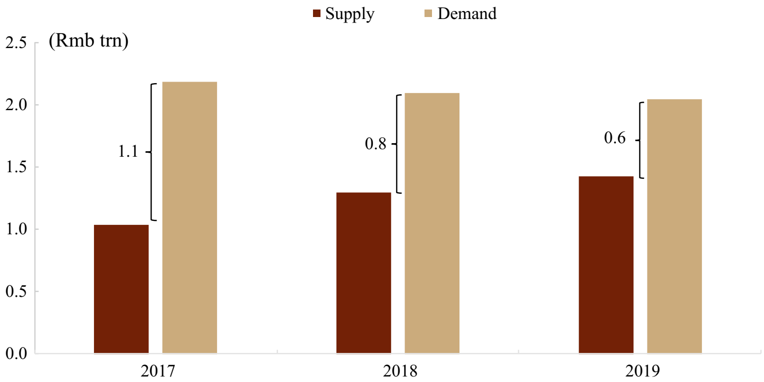


Fig. 4.5 Supply and demand of green investment in China (2017–2019). *Source* China Green Finance Progress Report, CICC Global Institute

4.4.1.2 Concentration of Green Financial Support in Certain Sectors

From the perspective of financing structure, certain sectors account for an excessively high proportion of China's green investment and may affect the amount of green investment in other sectors. For example, green credit loans accounted for over 90% of overall green financing tools in 2018–2019, and more than 40% of the green credit loans went to the transportation sector in the 2 years (Fig. 4.6).

The high concentration of green investment in the transportation sector led to a mismatch in the supply and demand of green funding. The power sector has the highest need for green investment and financing, while the building sector has the third highest need after the transportation sector. This implies that the current

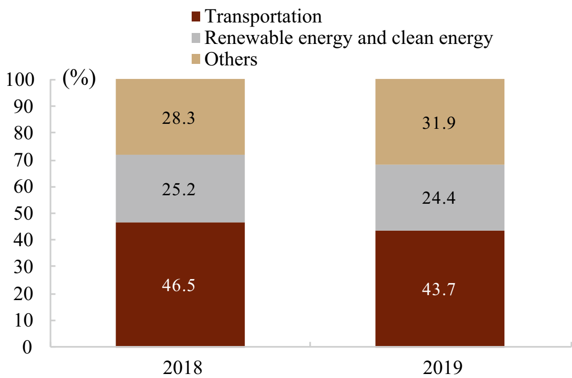


Fig. 4.6 Breakdown of green credit loans in China (2018–2019). *Source* PBoC, CICC Global Institute, CICC Research

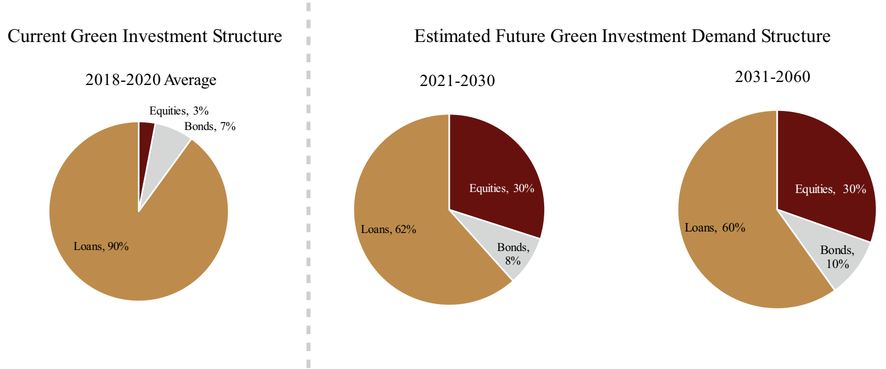


Fig. 4.7 Green credit loans account for about 90% of green financing, and sharp change in the demand structure of green financing is needed. *Source* Wind Info, CICC Global Institute, CICC Research

green financing tools have not yet covered the industries with large green investment demand, and that the allocation of green funding does not match the green development needs of the entire society.

4.4.1.3 Unable to Meet Diversified Financing Needs with Limited Tools

In addition to the high concentration of green investment in select sectors, the development of green financial tools in China is also lopsided. From 2018 to 2020, green credit loans accounted for about 90% of total green financing in China, whereas green bonds and green equities only accounted for 7% and 3% respectively (see Fig. 4.7 left side)[10,11]. However, we estimate[12] that green equities and green bonds will account for about 40% of the green investment demand after 2030, which differs sharply from the current financing structure (see Fig. 4.7 right side). The dominance of credit loans and the limited availability of other green financial tools will partly depress green investment demand.

[10] China Chengxin International Credit Rating.

[11] https://m.21jingji.com/article/20201229/herald/e43125877848294726df12e3caab7ecb_zaker.html.

[12] We assume the financing structure remains unchanged for Chinese companies, with new technologies adopting the financing structure of listed companies and older technologies relying on credit loans and bonds for financing.

4.4.2 Lack of Widely Accepted Green Standards

4.4.2.1 Absence of Unified Domestic Standards

Domestic green standards differ for various financial products, and several standards are not aligned with the carbon neutrality target. For example, the People's Bank of China has removed "clean coal utilization" and other projects related with fossil energy from the catalogue of projects supported by green bonds released in July 2020. Nevertheless, this remains included in other green financial standards, such as the guided catalogue for green credit loans released in 2019. This leads to an inconsistency in the standards of China's green financial system, and some of the green projects listed in the catalogue do not meet the zero-emission requirement of the carbon-neutrality target.

Discrepancies in standards and definitions also occur within the same financial tools because of multiple regulations. While the standards for green credit loans are relatively mature, they still differ in some areas. For example, nuclear power projects qualify for green finance according to the National Development and Reform Commission and the People's Bank of China, but are not included in the green finance catalogue from the China Banking and Insurance Regulatory Commission. In addition, the People's Bank of China, the National Development and Reform Commission and the China Securities Regulatory Commission in July 2020 issued an exposure draft for the catalogue of green-bond supported projects, which defined green bonds for the first time and set out the criteria. However, the finalized document has not been issued yet. In terms of green equity, it is still in its infancy with no clear definition or standards established in China.

4.4.2.2 Domestic Standards for Green Finance Still Below International Level

The domestic criterion gives a narrower definition to green credit loans than the international definition. To prevent greenwashing, China narrowly defines green credit loans as those for developing green industries and reducing carbon emissions, whereas the international standards of green finance tend to include loans for the green transformation of high-emission industries, and loans that consider environmental risks in the credit lending process (Table 4.2).

For green bonds, despite the similarity in definition, classification and voluntary principles, domestic standards for green bonds differ from international criteria in project eligibility, use of proceeds and third-party assessment, etc. For example, green-bond supported projects in China almost do not cover climate adaptation or green service (such as climate monitoring and warning systems or trading services for environmental rights), suggesting a relatively narrow market coverage. In addition, the National Development and Reform Commission allows proceeds raised

Table 4.2 Comparison between China's green loan standards, the green loan principles and the equator principles

Green loan standards			
	Green loan principles	Equator principles	China green loan standards
Aim	Promote and support environmentally sustainable economic development	Ensure that the financing projects are developed in a socially and environmentally responsible manner	Promote green economic development, prevent climate and environmental risks
Definition	Loans designed to finance or refinance new or existing "green projects"		Loans issued by financial institutions to corporates (institutions) or other organizations that can act as borrowers according to national regulations for supporting environmental improvement, efforts to combat climate change, resource conservation, and investing in projects in environmental protection, energy conservation, clean energy, green transportation, green buildings, etc.
Restrictions for the purpose of the loan	Full loan for "green project"; the "Green Loan Principles" set out a non-exhaustive list of 10 types of green projects; the project should be credited to a dedicated account or tracked in other ways	It is suitable for new project financing with a total cost of more than US$10mn in various industries around the world, as well as the project financing related to expansion of old projects and the project financing related to upgrading existing equipment that may have a significant impact on the environment and society. Refuse to offer loans to projects that violate Equator Principles	Require accurate proof that the use of green loans meets the requirements of the standards, and classification of the industry and loan quality of the green loan undertaker. Explanations on the loans of enterprises with major risks such as environment and safety risk are needed

(continued)

Table 4.2 (continued)

Green loan standards			
	Green loan principles	Equator principles	China green loan standards
The impact of borrowers' behavior on loan pricing	The impact of borrowers' behavior on green loan pricing is not considered	The impact of borrowers' behavior on green loan pricing is not considered	The impact of borrowers' behavior on green loan pricing is not considered
Censorship/report	Borrowers should keep records of the green loan projects, including project descriptions, allocated amounts, expected impacts, etc. An external review is recommended but not required	According to IFC's environmental and social screening criteria, EPFI is divided into categories A, B, C based on the potential impacts and risks of the projects to be financed. EPFI conducts environmental and social assessment (ESIA) on categories A and B, which is reviewed by environmental or social experts who have no connection with the borrower, and reports its implementation process and experience to the public at least annually	On the basis of self-evaluation of data quality management mechanism or data accuracy, financial institutions shall submit an application for number reporting, and report the special statistical data of green loans to the financial statistical monitoring and management information system according to the standards after being confirmed by the People's Bank of China

Source LMA, IFC, PBoC, CICC Research

from green bonds to repay bank loans and replenish working capital, while international standards stipulate that all the proceeds from green bonds should be used in green projects. Moreover, projects need to be assessed by professional environmental evaluation institutions and third-party institutions to determine whether they meet the green standards before international green bonds can be issued. After the bonds are issued, institutions should monitor and evaluate the use of funds as well as their contribution to energy saving and emission reduction, which should enable the market to evaluate green bond issuers and the environmental performance of projects funded by green bond issuances. However, China has not provided clear guidance on these areas.

To better support the development of green finance, the government is currently working on the green standards that are aligned with international criteria and unifying the standards for different green financial products. We anticipate the unified standards will be released shortly.

4.4.3 Defects in Green-Information Disclosure System

A well-established green-information disclosure system is the basis of decision-making strategies about green products and preventing information asymmetry such as greenwashing. Green-information disclosure system includes two aspects, namely green-information disclosure for companies and for assets held by financial institutions, equity investment institutions, etc.

China's green-information disclosure system suffers from a number of issues, including lack of mandatory requirement, absence of unified standards and unclear relationship between companies, financial institutions and regulators.

4.4.3.1 Lack of Mandatory Requirement on Green-Information Disclosure and Unified Standards

Listed companies are facing problems of unclear standards and limited coverage of green indicators for green-information disclosure. In 2016, seven regulators including the People's Bank of China issued Guidelines for Establishing the Green Financial System, proposing to establish and improve a mandatory green-information disclosure system for listed companies with a three-stage implementation plan. However, there was still no clear or unified standard of green-information disclosure for listed companies in China as of 1Q21. For example, listed companies included in the CSI300 Index rely on numerous guidelines to compile their social responsibility reports, such as guidelines from the Shanghai Stock Exchange, the Global Reporting Initiative, the Chinese Academy of Social Sciences, and the Hong Kong Stock Exchange. The lack of unified, comparable and quantitative guidelines leaves room for data manipulation and selective disclosure, thus failing to provide comprehensive and reliable green information for investors. Moreover, even though the proportion of listed companies voluntarily disclosing ESG information has climbed in recent years in China, the range of green information disclosed is still far smaller than overseas peers, and mandatory information disclosure is only confined to selected environmental indicators such as air, water and solid waste.[13]

For green bond issuers, the biggest issue is the absence of unified standards for green-information disclosure. The People's Bank of China, the Shanghai Stock Exchange, the Shenzhen Stock Exchange and the National Association of Financial Market Institutional Investors have all released standards on information disclosure for green bonds, providing many but ununified disclosure mechanisms in effect for different types of green bonds. Notably, China has set clear criteria for information disclosure for green financial bonds, requiring quarterly disclosure on the use of proceeds raised, the incremental green projects invested (amount and number) and fund management, as well as annual disclosure about the environmental benefits from the projects invested. Other types of green bonds are also mandated to disclose

[13] ESG data in China: Recommendations for Primary ESG Indicators.

related information, but requirements are not clear in terms of exactly what categories of green information should be disclosed, leaving room for improvement.

In addition, there is a lack of unified standards and effective supervision for non-listed companies (except for heavy-polluting companies). Third-party institutions responsible for certifying green enterprises and quantifying the environmental benefits brought by green projects are also not in place.

In terms of financial institutions, there is no mandatory green-information disclosure mechanism in effect. Various regulators have provided guidelines on green-information disclosure for key entities in the financial markets, such as banks, insurance companies and funds. Requirements have also been made for banks to strengthen ESG information disclosure and fund managers to provide self-evaluation reports on green investments. However, a mandatory green-information disclosure mechanism is absent for banks, asset management companies or equity investment institutions such as PE and VC firms in most regions of China. There is also no quantitative indicator for performance evaluation, i.e. exposure to green assets, the proportion of green funds in total funds, operating models or development targets. Moreover, actual use of funds and their environmental benefits are not effectively supervised or evaluated.

4.4.3.2 Unclear Relationship Between Companies, Financial Institutions and Regulators in Green-Information Disclosure System

Close cooperation among companies, financial institutions and regulators is essential to establish an effective green-information disclosure system that monitors and shares green information. However, the relationship of the three parties and their respective responsibilities in the green information disclosure system are not well defined.

The development of green-information disclosure system in China should address the absence of an incentive mechanism, and the unclear division of rights and responsibilities, in our view. Companies, financial institutions and regulators all play critical roles that could potentially affect each other in the green-information disclosure system, and if any of the three fails to function properly, it may render the entire system ineffective. For example, it may become challenging for regulators to design a well-functioning green information disclosure system if companies are not aware of the necessity of disclosing green information voluntarily. Lack of unified standards from regulators makes it more difficult for financial institutions to carry out green assessment, which may further impede the green transformation of companies if financial institutions are not interested in investing in green financial products due to inadequate information. In addition, the relationship and responsibilities of the three are not well defined in the green information network: A number of financial institutions have taken the corporate responsibility of reviewing information disclosure, thus increasing their cost of investing in green projects. We believe the green information network and investment process will become more streamlined if companies and third-parties can share this cost in the future.

There also lacks an environmental data sharing mechanism among companies, financial institutions and regulators. In China, governments, third-party institutions and companies cannot effectively share environmental data among themselves at present, and environmental regulators have not yet started data sharing with financial institutions, which hinders development of the green investment market and full information disclosure. Some of the institutions have cited confidentiality as the reason for not disclosing information in the past, but we believe that disclosure of green information is inevitable amid the clear target for green development. From our point of view, earlier information disclosure will facilitate troubleshooting and system improvement, which can help reduce losses caused by environmental and other risks.

4.4.4 Weak Guidance from Financial Institutions

4.4.4.1 Upside Potential in Guidance from Domestic Financial Institutions

Funding support from financial institutions such as banks, insurance firms, investment banks and asset management firms is indispensable for the green transformation of industrial companies. However, the penetration rate of green investment ideas remains low in the investing activities of domestic financial institutions. According to the 2021 Global Institutional Investor Survey released by MSCI, 75%, 59% and 56% of the investment managers from Canada, Japan and Europe respectively have adopted ESG frameworks in their asset management, while the penetration of ESG investing was as low as 16%[14] among Chinese fund management institutions in 2019.

Insurance firms, pension funds and social security funds are inclined to invest in the long term, which is a natural fit for the long development cycles of certain green projects and green companies. However, the participation of long-term funds in green investment is limited in China. In mature markets overseas, long-term funds, in particular large institutional investors such as pension funds and insurance firms, are frontrunners in ESG investing due to their large investment, long investment cycle and demand for entrusted management. Their investment concept and requirement for asset management institutions usually set an example for the entire market. However, long-term funds in China are relatively cautious about ESG investing. Data from UN-PRI (Principles for Responsible Investment) shows that only two Chinese pension funds are signatories of the UN-PRI as of March 2020, showing that ESG investing concepts are still relatively new to Chinese insurance and pension institutions.

[14] ESG investment survey by the Asset Management Association of China in 2019.

4.4.4.2 Coordination Mechanism is Absent for Financial Institutions Looking to Play a Guiding Role in Green Finance

The lack of a coordinated guidance mechanism for Chinese financial institutions may weaken financial institutions' ability to guide corporate green development. For example, commercial banks can guide green transformation of companies through two measures, namely providing credit loan support for green companies or green projects, and restricting credit loans for non-green projects such as those from high-emission industries, forcing them to conduct green transformation. However, it remains voluntary whether banks guide the green development of companies (such as adopting the Equator Principles). As a result, some banks may seek short-term economic returns by providing loans for high-emission projects rejected by others, thus impeding other banks from guiding the green development of companies. A unified coordination mechanism may provide constraints on the behavior of all commercial banks, and thus contribute to concerted efforts to channel funds for supporting green projects.

4.5 Turning Challenges into Opportunities: How to Address the Weaknesses in China's Green Finance?

Achieving carbon neutrality is a challenge as well as a new opportunity for China, and green finance needs to play a vital role in serving and guiding the green transformation of the real economy. Given the weaknesses in China's green finance and its need to cut carbon emissions, we review international experiences and offer corresponding suggestions on the policy-making for the development of green finance.

4.5.1 Setting a Unified Green Standard in China

A well-established standard is essential to the sustainable development of China's green financial system. Currently, the system has issues with multiple supervisions, inconclusive regulations, and incompatibility with international standards. Therefore, we suggest improvements for setting a unified green standard in China from these three perspectives.

First, clearer and more systematic standards for green financial products should be established. In the short term, the government may need to first establish a unified standard for financial products, laying the foundation for green financial products' healthy and sustainable growth. In the medium and long term, we believe a systematic green financial system framework should be built to reduce differences in the classification standards of green products and boost balanced development between different types of financial products, thus bridging the gap between supply and demand in green investment. **Second, domestic standards should align with international standards.** For green credit loans, the internationally accepted idea of sustainability-linked loans could be gradually introduced to eliminate the difference between Chinese and global standards. With respect to green bonds, we suggest that the government could set a green bond standard that is aligned with international standards, expanding green bonds' coverage and establishing a green bond system with external assessment, information disclosure as well as duration management. **Third, introducing third-party attestation institutions should also be an important measure, especially in bringing in international institutions.** Third-party attestation institutions play a vital role in promoting the healthy and sustainable development of China's green financial system, enhancing a green company's reputation and the attention from corporate and investment institutions through the independent attestation reports. In addition, independent third-party attestation institutions will help reduce information asymmetry in financing and investment, and lower the credit risk and information searching costs of China's green financial system. Moreover, if third-party attestation institutions adopt international standards, Chinese green financial products could be more recognized by the global market and be more attractive to investors overseas. This may further reduce financing cost of green industries and improve availability of funding.

4.5.2 Establishing a Binding Green-Information Disclosure Mechanism

Given the green-information disclosure mechanism and industry attributes, we offer the following suggestions. For listed companies, mandatory green-information disclosure mechanism should be improved, and a clear and quantitative green-information disclosure standard system that is in line with international standards needs to be established. For green bond issuers, barriers between regulators should be removed to establish a unified information disclosure system for green bond issuers. For non-listed companies, improving the information disclosure mechanism and building an information sharing platform are the key ways to reduce information asymmetry in the launch of green products. For financial institutions, establishing a green-information disclosure mechanism will help to quantify and assess green products' environmental benefits with regards to the participants of the green finance market.

4.5.3 Improving Incentive Policy to Boost the Overall Development of Green Financial Market

We attribute the gap between supply and demand of green investment to the low ROI, long investment cycles and high risks associated with green investment projects. To further encourage the development of green finance, the People's Bank of China, China Banking and Insurance Regulatory Commission and China Securities Regulatory Commission can introduce incentive policies from the following aspects (Table 4.3). **From the liability side**, expanding funding sources and reducing liability cost should be considered to address issues related to term matching and asset pricing. **With regard to the credit cost side**, the government should expand the green insurance product portfolio, initiate and invest in guarantee funds, reduce the cost of bank credits and credit debt defaults, and support credit financing products through insurance or guarantee funds. **Regarding taxation**, preferential taxes for green investors could be introduced to enhance their interest in green investment. **From the capital cost side**, it is important to reduce capital consumption of green products. **From the trading cost perspective**, potential suggestions could be lowering administrative approval requirements and increasing exit potential of green projects.

4.5.4 Strengthening Education of Green Concept; Financial Institutions Offering Both Services and Guidance

The support of long-term funds and asset management institutions as well as the general public is indispensable for the long-term sustainable development of the green industry. To better facilitate green development, financial institutions need to guide funds towards green projects, which relies heavily on education about green investment. One of the typical fields that requires guidance from financial institutions is ESG investing. Therefore, we propose the following policy suggestions following the experience overseas.

Firstly, based on the nature of funds and institutions, mandatory administrative requirements and market-oriented incentives could be used to guide fund flows into the ESG field, thereby enhancing the awareness of the public and asset management institutions about responsible investment as well as long-term investment. It also guides the green finance system to shift from the top-down government-dominated ESG investing into the market-oriented stage. Secondly, we also encourage asset management institutions to voluntarily join the Principles for Responsible Investment (UN-PRI). The government could encourage asset management institutions to join responsible investment organizations or establish their own ESG investment systems in the near term and offer favorable policies. For example, the government can open green channels for product application for asset management institutions incorporating ESG principles, and/or provide them with additional credit in performance reviews.

Table 4.3 Measures for transforming positive externalities into business incentives

		Liability side (expanding sources and reducing costs)	Credit cost	Tax cost	Capital cost	Transaction friction cost
Financing	Loans	Discount interest, reloans, green bond issuance, ABS			Reduce asset risk weight and reduce capital consumption; revitalize green loan assets by issuing green loan ABS	Further simplify the approval process, reduce the cost of pre-loan environmental certification, environmental protection technology testing and post-loan supervision through the popularization of rating agencies
	Bonds	Reloans priority		Consider halving interest income tax	Banks or bank wealth management which invest in green bonds will receive certain preferential treatment in terms of capital consumption, and the balance sheet will no longer occupy 100% of the capital	Certain preferential policies are also given to market-oriented institutions for setting up green investment funds/asset management products. For example, setting up special approval channels to improve approval efficiency

(continued)

Table 4.3 (continued)

		Liability side (expanding sources and reducing costs)	Credit cost	Tax cost	Capital cost	Transaction friction cost
	Equity	Lower the threshold of qualified investors for qualified green private equity and venture capital funds; exempt the single-layer nesting regulations for green private equity investment funds; for qualified green PE/VC, the government directly invests as an LP, and can moderately extend the fund evaluation period; guide long-term funds such as pension funds, social security funds, endowment funds, and insurance funds to invest in qualified green PE/VC institutions; introduce overseas capital focused on investing in green industries		Provide tax relief and other supporting policies for green PE/VC institutions with high participation in green investment and outstanding environmental benefits		Further promote the development of regional stock exchange markets and the pilot PE secondary market, prioritize and encourage qualified green companies to list on the NEEQ or exchange listings, and prioritize the pilot qualifications of PE/VC institutions with higher participation in green equity; establish green board and green channels for green enterprise main board listing, streamline the conditions of green enterprise refinancing on main board and Sci-Tech board issuance, explore and optimize the stratification and transfer mechanism of the NEEQ green enterprise; include brokerage green project participation in the assessment

(continued)

Table 4.3 (continued)

		Liability side (expanding sources and reducing costs)	Credit cost	Tax cost	Capital cost	Transaction friction cost
Investment	ESG and green funds	Speed up the entry of long-term funds such as social security, pension funds, and insurance funds into the market, and guide long-term funds to incorporate ESG principles into investment decisions as soon as possible		Exemption of relevant capital gains tax for investment companies that meet the requirements for green exposure ratio and holding time		Asset management institutions that practice ESG investment are given certain policy preferences in product issuance, such as simplifying the product approval process and setting up green channels
Insurance or guarantee fund		Subsidies are given to insurance companies to support them in providing discounts to low-carbon emission companies	Green insurance or guarantee funds play a leverage role by reducing the cost of credit for asset holders	Premiums paid by companies can be deducted before tax	Reduce the solvency requirements of green insurance business and reduce the capital consumption of such business type	
What measures are currently being implemented		Currently relies on policy support methods including interest discounts and reloans	Guarantee		Reducing the risk weight of green loan assets has been piloted in some banks (Huzhou Bank)	The catalog of green loans and bonds helps to identify whether the project is green and speed up the approval process

(continued)

Table 4.3 (continued)

		Liability side (expanding sources and reducing costs)	Credit cost	Tax cost	Capital cost	Transaction friction cost
Overseas cases		The British government established Green Investment Bank at the end of 2012 to provide financial support for green companies and green projects. In 2011, the British government invested GBP3.87bn to establish the International Climate Fund, which aims to promote private investment in sustainable development and build a low-carbon investment market. As of April 2016, the fund's AUM had reached GBP5.8bn		In 1993, the US government initiated Qualified Small Business requirement. If a qualified investor invests in a small enterprise under this standard and holds it for more than 5 years, the investor can get up to 100% capital gains tax relief to increase investors' enthusiasm for small enterprises and start-ups, which also meets the financing needs of small enterprises for long-term funds to a certain extent		In 1980, the US Congress established the BDC (Business Development Company) system. The shares of PE/VC institutions identified as BDC are allowed to be listed and traded, and investors can benefit from tax incentives, which broadens the financing channels for PE/VC institutions and indirectly promotes the development of green equity investment. At present, some BDC institutions have gradually extended their investment fields to green industries

Source China Banking and Insurance Regulatory Commission, Ma, Jun. Case Studies of Green Finance in China (2017), CICC Research

4.5.5 Incorporating Environmental Risks into Prudential Regulations

Amid the green transformation of the economy, financial regulators should pay attention to two kinds of environmental risks: extreme climate change's impact to the real economy, and the erosion of valuations of traditional-energy companies, thus weighing on the stability of financial institutions.

When managing environmental risks, financial regulators can release prudential regulatory policies and incorporate systemic environmental risks into the macro regulatory framework. For example, the central bank of Brazil sets different reserve requirement ratios according to the amount of green loans issued by private banks. It also requires commercial banks to incorporate environmental risks into their governance framework, and assess environmental risks when calculating capital demand, thus internalizing the transition risks of carbon-intensive assets by incorporating environmental risks of carbon-intensive assets into macro prudential indicators.

Financial regulators can add environmental factors into the asset evaluation criteria. The central banks of Switzerland and Norway have included ESG indicators in the evaluation criteria for asset investment and collateral. The central bank of Norway manages the government pension based on the ESG principle, purchases green bonds as proprietary investment, and has stopped investing in assets that are related to coal production or companies that seriously damage the environment. The central bank of Switzerland adopts ethical standards for foreign equity purchases. Similar principles can also be applied to the collateral business of the central bank. For example, the central bank can stop taking collateral with serious environmental damage, or offer differentiated haircuts based on the collaterals' environmental risks.

Regulators also need to establish a risk exposure and disposal mechanism for brown assets[15] to maintain financial stability amid the green transformation. We should prevent impacts from transition risks on the real economy and the financial system. To assess the financial system's exposure to environmental risks and the impact of the green transition, the central bank should regularly assess the financial institutions' tolerance to impacts. During the green development, the value of traditional assets with high carbon emissions may drop, affecting the real economy and the financial system (this is a transition risk). By assessing the financial institutions' tolerance to such impacts, the central bank can effectively improve the information transparency of green finance, internalize environmental risks into financial risks, and allow investors to understand the investment risks they are facing. This measure can also help fine-tune the prudential regulatory framework, identify possible weakness in the system and incorporate it into the regulatory mechanism.

[15] Brown assets refer to assets related to high-emission industries, which are traditionally heavy industry and manufacturing industries.

Chapter 5
Green Technology: From Quantity to Quality

Abstract Energy is the foundation of the green technology industry, and fossil fuel has built the current global energy and industrial system. Under the goals of emission peak and carbon neutrality, all countries need to change their energy structures to achieve net-zero carbon emissions, which in essence represents a revolution for energy. The core of carbon-neutral technologies is the transformation in the energy supply side. Without the feasibility and affordability of zero-carbon technologies, it would be impossible for the consumption side to put those technologies into practice. Considering the green premium of the current electricity supply vs. non-electricity energy supply, it is still difficult and costly to achieve carbon neutrality based on existing technologies. Hence, reducing costs will be the main development direction of energy technologies in the future. In the long term, energy technologies will demonstrate significant variations over time, which gives a perspective to this report. We will analyze the possible development of different technologies in terms of potential cost savings, and investigate the development of technological routes under constraints of scheduling and resources for China's carbon neutrality initiative. We believe the falling cost of carbon neutrality technologies will eventually be the main driving force for large-scale application. In the power industry, photovoltaics (PV) and energy storage are expected to reach tariff parity with thermal power (or a zero green premium) by 2028. For non-electricity energy supply, a higher electrification rate will promote CO_2 emissions reduction in consumer, construction, and toll road transport sectors, and then the net-zero carbon emissions of transportation and manufacturing industries will be achieved by using hydrogen energy and carbon capture technologies ultimately. Although China's mission to achieve carbon neutrality in 40 years is a challenging undertaking, it is ample time in which technological developments and breakthroughs are possible. For example, the technological development route would change if nuclear safety can be improved on the back of advanced nuclear energy technologies, as well as the CO_2 obtained via carbon capture technologies can be utilized and become a revenue source. In addition, if the photoelectric conversion efficiency exceeds 30%, the hydrogen energy cost will continue to drop.

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_5

5.1 Technological Breakthrough and Carbon Neutrality

5.1.1 Why Do We Need a Technological Breakthrough?

Reducing CO_2 emissions from energy projects is crucial to China's carbon neutrality. According to the CICC macro team, the energy sector accounts for 90% of CO_2 emissions in China (before factoring in carbon sinking).

With existing technologies, it is costly to achieve carbon neutrality in the energy and manufacturing industries, which makes costs reduction via technological advancement the key to reducing the green premiums. According to our estimation, green premiums will stand at 17% in the power industry and at 175% in other industries in 2021. We attribute the high green premiums to the elevated cost of clean energy, and if there are no technological advancements, the cost of the transformation towards carbon neutrality will be high. Concerning the current situation, there is still room for improvements in the efficiency of clean power projects. Green hydrogen energy and carbon capture technologies need to further increase the technological maturity and expand industrial application, hence reducing the cost of green energy via three fundamental technological routes: economies of scale, material replacement, and efficiency enhancement.

The technological transformation will bring changes in cost. According to the sales data of wind and photovoltaic power companies, we estimate that the costs of solar and wind power dropped 89% and 34% over 2010–2020 due to developments in non-fossil energy technologies (Fig. 5.1). This means that the costs of solar and wind power fell 13% and 7% each for every 100% increase in the installation of power generation facilities. In contrast, the costs of coal, petroleum, and natural gas continued to fluctuate during this period, as shown by an increase of about 45% in China's coal price compared with the lowest price recorded in 2015 following the short supply. China has long focused on the cost advantage in energy supply (its

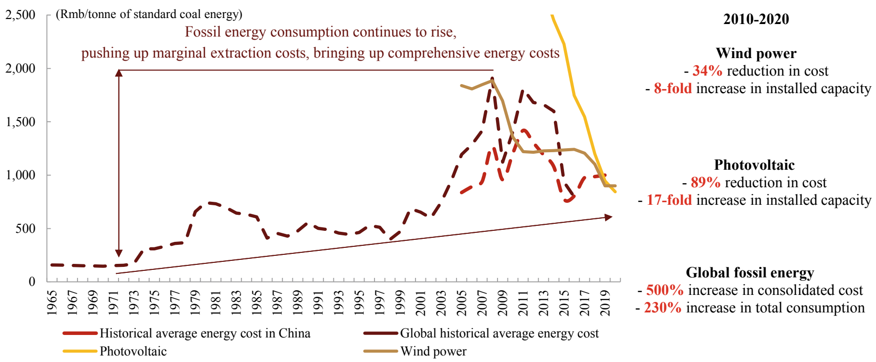


Fig. 5.1 Costs of fossil energy, wind power, and photovoltaic power. *Source* BP, Solarzoom, Corporate filings of wind and solar power companies, CICC Research

electricity price was 14%–64% lower than those in developed countries in 2018), and as alternative-energy costs drop following the use of advanced technologies, the costs of wind and photovoltaic power projects have fallen short of the costs of coal-fired power projects in China. These are all sensible changes brought by technological advancements.

Therefore, to reach an emission peak in 2030 and achieve carbon neutrality in 2060, transformations from technological maturity to industrial maturity are needed for various carbon-reduction and carbon-neutral technologies in the next 4 decades to pave the way for China's carbon neutrality. Currently, China is still confronting high green premiums in various industries. If green premiums are forced to be reduced without technological advancements, the significant social costs will hinder the transition to carbon neutrality.

5.1.2 What Can Become Carbon Neutral by Technological Advances and What Cannot?

Carbon neutrality will be difficult to achieve if the energy supply cannot realize net zero carbon emissions, which suggests the development of energy technologies is the foundation for carbon neutrality. In addition, since the growth of new economies also relies on electricity supply, if China can realize net zero carbon emissions of electricity generation through solar, wind, hydro, and nuclear, the growth of new economies will not be bound by emission reduction targets. We should also recognize that although energy supply depends heavily on technological development, public policy also plays an important role in end-market consumers' choosing low-energy consumption models. Cost is only one of the factors that consumers consider when they choose low-energy consumption models. This means that companies may not spontaneously shift to zero-carbon-emissions technologies even when the green premium reaches zero. As a result, reducing carbon emissions in consumer-related industries, such as transportation and heating, requires not only technological advances but also additional policy tailwinds.

5.1.3 What Are the Technological Routes for the Carbon Neutrality Initiative? What Are the Constraints?

In the choice of the technological routes for 2020–2060, economic optimization of energy transition can be achieved through technology selection (i.e., easy to difficult). In addition to cost, resource constraints and the application scenario will also influence consumer choices in technology.

Net zero emissions in the power industry should first consider multiple energy sources to help reduce the electricity generation cost. Photovoltaic and energy storage should be the major emphasis in electric supply, but the complementary smart power grid technologies that utilize multiple energy sources are also crucial. Additional policy tailwinds for power grid and energy storage technologies and a higher proportion of non-fossil energy are pivotal in helping the power system operate in a safer and steadier way and reducing the overall electricity cost.

Carbon neutrality technologies for activities other than power generation hinge on areas where the technologies are utilized. Outside the power sector, energy for other industries is used in various areas and the technologies utilized are not 100% transferable with each other. As a result, companies need to use different energy technologies in different applications. Based on the trajectory of cost reductions, we believe the cost of hydrogen energy-enabled transportation will drop to a level acceptable to consumers by 2035, while industries are more likely to achieve carbon neutrality via the use of carbon capture technologies.

To summarize the technology routes for carbon neutrality, photovoltaic and energy storage technologies will be the major technological foundation in the power sector, with hydrogen accompanying carbon capture in the non-power sector. We believe China can achieve its CO_2 emission target by 2030 through multiple technologies that reduce energy consumption and CO_2 emissions. Then we expect the power-generation industry to reach net zero emissions based on the photovoltaic-skewed power system with multiple energy sources. In addition, the supply of cleaner and cheaper electricity should lead to greater electrification in industries such as toll roads, railways, construction, and some manufacturing industries. For hard electrification fields such as heavy transportation, aviation, and the chemical industry, net zero carbon emission could be achieved through hydrogen and biofuels. Other manufacturing industries may ultimately achieve carbon neutrality by using carbon capture technologies.

Summing up the policy implications of technological routes for the carbon neutrality initiative, we believe a technological breakthrough is possible given the evolution of existing technologies, but several industries (such as hydrogen power-enabled industrial heating) probably will not be able to reach a zero green premium on the back of existing technological routes. These industries will continue to have positive green premiums and rely greatly on policy tailwinds for their carbon neutrality efforts. From our point of view, China should first propel the development of non-fossil energy to at least mitigate the CO_2 emission problem in non-electric energy sectors through increasing the electrification rate, and then promote the industrialization as well as scale-up of the use of hydrogen energy over 2020–2040 and encourage the use of carbon capture technologies over 2040–2060 to make zero-carbon-emissions technologies feasible and affordable in all industries. The technological route to realizing carbon neutrality in energy is shown in Fig. 5.2.

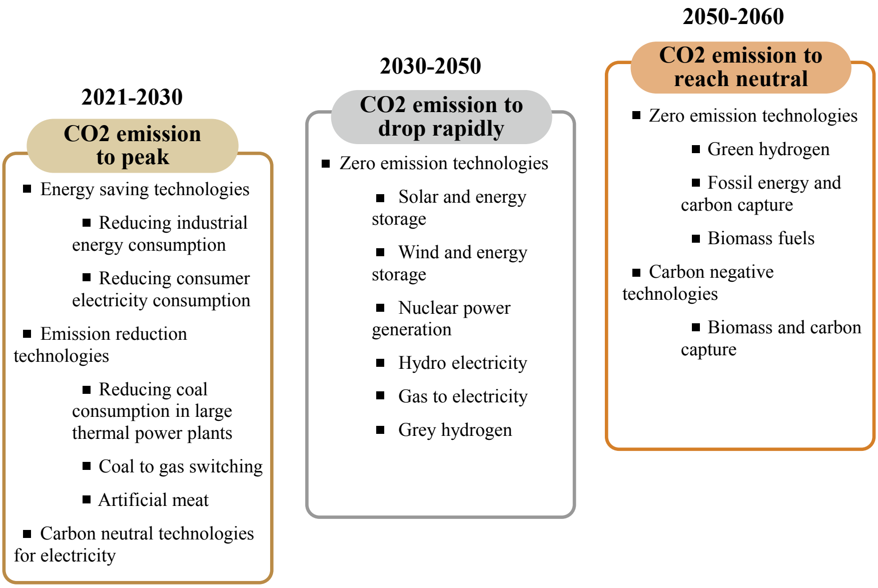


Fig. 5.2 Technological routes for the carbon neutrality initiative. *Source* CICC Research

5.2 Cost is a Touchstone for the Development of Technology

5.2.1 What Kind of Technologies Are Capable of Reaching Emission Peak and Carbon-Neutral as Planned? What Are the Differences in the Choices of Various Technological Routes?

At the stage of emissions peak, the mainly adopted technologies should be able to help to reduce CO_2 emissions as much as possible. To pursue carbon neutrality, more advanced technologies are required. China's forests naturally form carbon sinks, but their energy density and overall capacity remain relatively low. Therefore, net zero carbon emissions technologies and even negative carbon emissions technologies must be applied in energy and manufacturing industries to achieve carbon neutrality. In the long term, we should take the current costs of technologies as well as the potential of reducing the costs of these technologies into consideration.

5.2.2 *Three Measures to Reduce the Cost of Developing Energy Technologies*

In retrospect of the history of technological development in energy, three main measures have helped to reduce technological cost: economies of scale, material replacement, and efficiency enhancement. Although photovoltaic, electrochemical EV batteries, and hydrogen energy technologies remain controversial, these technologies continue to develop rapidly. The fundamental reasons behind the rapid development in these technologies lie in their manufacturing attributes. The costs of these technologies are likely to drop on the back of economies of scale, material replacement, and efficiency enhancement, while traditional fossil energy (such as coal, petroleum, and natural gas) due to their energy attributes may see costs

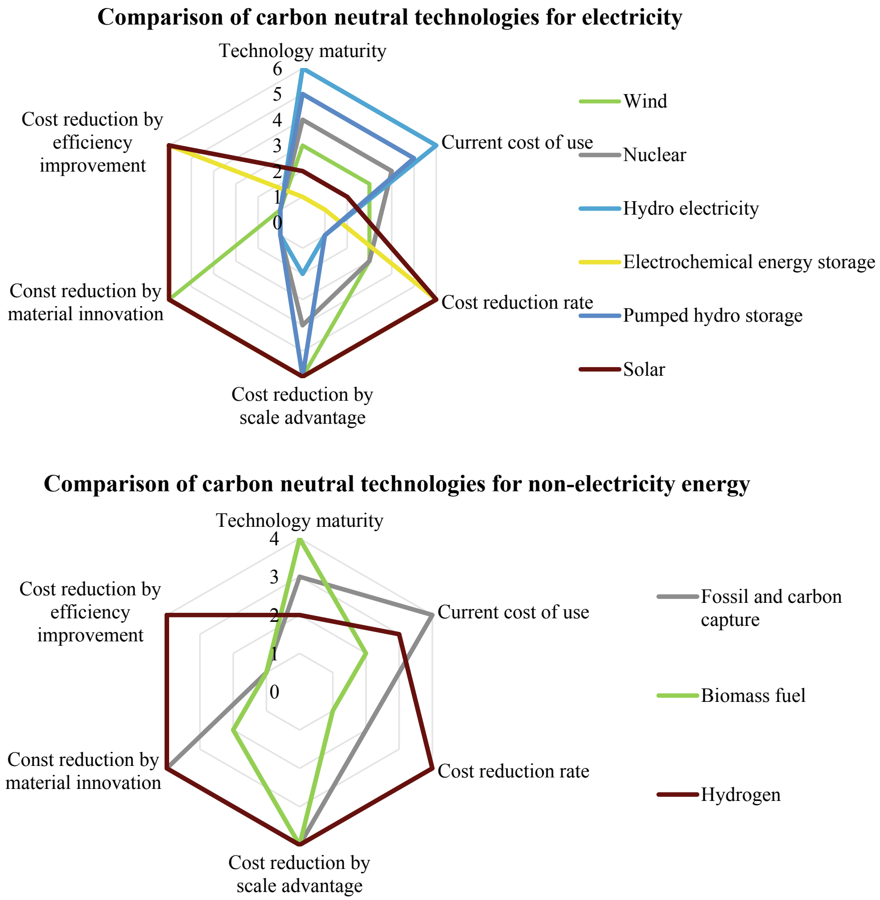


Fig. 5.3 Carbon neutrality technologies for use in power generation and other industries. *Note* A larger number indicates better performance. *Source* CICC Research

increase amid higher demand. As such, photovoltaic, electrochemical EV batteries, and hydrogen energy technologies will likely become pivotal energy technologies going forward. The multidimensional comparison of power sector and non-power sector's technologies for carbon neutrality is shown in Fig. 5.3.

In conclusion, energy-efficient and carbon reduction technologies are likely to contribute more to reaching the peak of CO_2 emissions in the coming decade. Among net zero emissions technologies, hydropower has the lowest cost, followed by wind, photovoltaic, and nuclear power, while pumped hydro storage projects have lower costs than electrochemical energy storage projects. The costs of photovoltaic and electrochemical energy storage technologies will fall faster than other technologies, thanks to efficiency enhancement, material replacement, and economies of scale. Concerning net zero emissions technologies for industries other than power generation, hydrogen energy and carbon capture technologies differ in maturity and cost, and neither has yet reached the commercial stage. Nevertheless, costs of hydrogen energy could be reduced through scaling, material substitution, and efficiency. Carbon capture technologies can also realize cost reduction via the first two methods. At the critical point for carbon neutrality, the cost of manufacturing hydrogen will likely drop rapidly as the electricity generation cost at photovoltaic projects may decline notably thanks to the electrolysis of water. As a result, hydrogen energy may realize price parity with traditional energy in the toll road industry and be put into use.

5.3 Existing and Potential Technologies for Net Zero Carbon Emissions and Carbon Neutrality Initiatives

5.3.1 Technologies to Help Cut CO_2 Emissions Focus on Reducing Energy Consumption and Shifting to Energy Technologies that Produce Lower CO_2 Emissions

Technologies that help thermal power stations reduce coal consumption: Thermal power stations can raise thermal efficiency to 45%, thereby reducing CO_2 emissions. Over the past decade, coal consumption for electricity generation at domestic power stations has dropped 27g per kWh to 306g per kWh. This implies that power stations cut 320mnt of CO_2 emissions in 2019 (equal to around 3% of full-year CO_2 emissions in China), as the annual amount of electricity generated was 4.6trn kWh. We estimate that domestic thermal power stations can reduce CO_2 emissions by 470mnt if coal consumption for electricity generation drops by 41g per kWh to the level recorded by the most advanced existing supercritical reheating thermal power stations in China (265g per kWh).

Replacing coal with gas: The coal-fired heating facilities in rural areas discharge multiple pollutants, including sulfur and nitrogen. They intensify the problem of scattered CO_2 emissions. Replacing 2t of coal with natural gas in the rural heating system can help reduce CO_2 emissions by 230mnt annually, according to the CICC commodities team.

Industrial energy-efficient technologies: During the 13th FYP period (2016–2020), energy consumption per industrial value-added at companies above the designated scale dropped 15.6%, meaning that these companies cut CO_2 emissions by 240mnt in the given time span. We estimate that industrial energy consumption will drop 14% by 2025, referring to the energy reduction target formulated in the *National New and High-Tech Green Development Action Implementation Plan* released by the Ministry of Science and Technology. As such, we estimate that industrial companies will reduce 220mnt of CO_2 emissions by 2025.

Technologies making home appliances more energy-efficient: The amount of electricity usage may continue to increase due to consumption upgrades. Nevertheless, the CICC home appliance team estimates that the growth rate of electricity used by consumers will decrease 2.4ppt annually due to the initiative to raise energy efficiency standards for home appliances. This suggests that electricity used by home appliances will fall 36.8bn kWh (down 3.2%) in 2021, meaning a drop of 36.7mnt in CO_2 emissions.

Cultured meat technologies help reduce CO_2 emissions of the animal husbandry industry: The CICC agriculture team estimates that replacing animal protein with cultured meat can reduce CO_2 emissions by 13mnt. Coupled with photosynthesis-enabled carbon sequestration during the process of planting soybeans, it could further enhance the effect of carbon sequestration.

Operating thermal power stations more flexibly: The flexible transformation of thermal power stations may slightly increase the CO_2 emissions per kWh of electricity generated, but it also will help power grids use additional net-zero-emission non-fossil energy, thereby reducing the overall utilization hours of coal-fired power plants and reducing CO_2 emissions of the entire power system.

5.3.2 Carbon-Neutral Technologies: Technologies that Help Achieve Zero-Carbon and Negative-Carbon Emissions

Predictions of cost drops of carbon-neutral technologies in the power industry are as follows: Concerning the zero-carbon-emissions technologies available to the power industry, electrochemical energy storage technologies may record the largest drop in cost, as the use of this type of storage is currently in its infancy; we estimate that the cost of photovoltaic technologies will drop 50% in the coming decade due to economies of scale, material replacement, and efficiency enhancement; the utilization rate of wind power projects is close to the theoretical limit, but because of increased turbine capacity and the domestic production of raw materials, we expect the cost of wind power technologies to drop 20%–30%; the mass production and domestic production of nuclear power projects is expected to generate more than 10% decrease in the cost of investment, and the drop in the cost of hydropower projects will be limited, as locations suitable for hydropower stations are scarce. The expected cost drop and core driving force of carbon-neutral technologies in the power industry are listed in Table 5.1.

Photovoltaic power cost forecast: With the use of perovskite technologies, the module efficiency is expected to reach 35% by 2030, in which the module cost will come in at Rmb0.9/W and the BOS cost will drop to Rmb0.8/W. Overall, we estimate that the CAPEX of photovoltaic power projects will drop to Rmb1.6/W by 2030. Assuming utilization hours remain unchanged, the photovoltaic cost has the potential of dropping to Rmb0.15/W in eastern China and Rmb0.2/W in western China.

Table 5.1 Falling costs of carbon-neutral technologies in the power industry

	2020 cost per kWh	Cost reduction pathway			2030 cost per kWh	2020–30 cost reduction rate
		Economies of scale	Material substitution	Efficiency improvement		
Power technologies (Rmb/kWh)						
Solar (western China)	0.31	√	√	√	0.15	+ + +
Solar (eastern China)	0.41	√	√	√	0.20	+ + +
Onshore wind	0.28	√	√		0.21	+ +
Offshore wind	0.61	√	√		0.40	+ +
Hydrogen electricity in Yunnan	0.25				0.25	–
Coastal nuclear	0.35	√			0.31	+
Biomass power	0.73				0.73	–
vs. National thermal	*0.37*				*0.37*	–
	2020 cost per kWh	Cost reduction pathway			2030 cost per kWh	2020–30 cost reduction rate
		Economies of scale	Material substitution	Efficiency improvement		
Grid technologies (Rmb/kWh)						
Pumped hydro storage	0.18				0.18	
Electrochemical energy storage	0.71	√	√	√	0.29	+ + +
vs. Thermal power flexibility	*0.14*				*0.14*	

Source Current electricity cost calculated based on data from China Electricity Council, corporate filings of wind, solar, hydro, and nuclear power companies, GGII, LEK Consulting, and cross-checked via electricity prices released by NEA and regional power grid companies; electricity cost for 2030 is a CICC estimate

Wind power cost forecast: We estimate that the cost of electricity generated by onshore and offshore wind power projects may have the potential to drop to Rmb0.21/kWh (based on the assumption that utilization hours will increase to 3,500h, construction cost will drop to Rmb5.8/W) and Rmb0.4/kWh (based on the assumption that utilization hours could reach as high as 4,000h, and investment cost could drop as low as Rmb12.5/W) to achieve price parity by 2030.

Hydropower cost forecast: Hydropower is currently one of the lowest-cost power sources in China. According to NEA, the average on-grid tariff of hydropower projects is low at less than Rmb0.25/kWh in Yunnan, Qinghai, Gansu, and Xinjiang. The current cost of hydropower equipment has stabilized in China, and given the CAPEX released by hydropower companies, we estimate that the construction cost of hydropower units that start operation after the 14th FYP period will increase to Rmb10–15/W. As upstream reservoirs will likely increase the utilization hours of hydropower units through region-wide scheduling, the overall cost of hydropower should remain stable in the future.

Nuclear power cost forecast: The cost of third-generation nuclear power units under development has exceeded Rmb0.35/kWh due to stricter safety regulations. (According to the corporate filings of power companies, the investment cost of China-made nuclear power unit Hualong One, which utilizes third-generation nuclear power technologies, stands at about Rmb16.4/W based on an operation period of 60 years and annual utilization hours of 7,500h.) The cost of nuclear power will likely decline, thanks to the domestic production of the third-generation nuclear power units, the mass-production of these products, better design, and shorter construction periods. Power companies hope to reduce the investment cost of third-generation nuclear power units to the level of second-generation nuclear power units (Rmb12.3/W).

Biomass power cost forecast: The cost of biomass power is high at Rmb0.73/kWh given the straw cost of Rmb300/tonne, the investment cost of Rmb10/W, and 7,900 utilization hours. According to International Renewable Energy Agency (IRENA), the equipment cost of biomass power units is unlikely to drop. Since the total volume of biomass resources in China is subject to the output of the agriculture, forestry, and husbandry industry, the grain safety program, and transportation (transportation's contribution to costs is high due to straw's low energy density), we believe the cost of biomass power will remain stable.

Pumped hydro storage cost forecast: We estimate that the cost of pumped hydro storage projects could reach about Rmb0.2/kWh (given the cycle efficiency of 75%, investment cost of Rmb6/W, and 2,500 discharging hours) with efficient power grid scheduling. Pumped hydro storage is also economically viable (current annual utilization hours are generally less than 1,000h, indicating substantial room for improvements). Construction of pumped hydro storage projects, similar with construction of hydro power projects, requires certain geographic resources and conditions. The cost of pumped hydro storage is not very likely to drop, due to limited locations for such projects and higher resident resettlement costs.

Electrochemical energy storage cost forecast: With the development of advanced battery technology, the cost of electrochemical energy storage technology has dropped notably. However, the cost is still at a relatively high level, Rmb0.6–0.8/kWh (the battery system cost is Rmb0.7/Wh; the total system cost is Rmb1.7/Wh;

cycle life is about 5,000 cycles). By 2030, the system cost may reach Rmb1/Wh. In addition, improved electrode materials and advanced maintenance technologies are expected to increase the cycle life of batteries to more than 10,000 cycles. As such, we anticipate the energy storage cost will drop to Rmb0.3–0.4/kWh.

Falling costs of carbon-neutral technologies besides power generation are listed as follows. Electricity substitution is the least expensive method to achieve net zero emissions in the non-power industries and may continue to benefit from the falling cost of clean electricity in the future. The cost of hydrogen energy may drop 70% as the result of economies of scale in the industrial value chain and the use of clean electricity in producing hydrogen via electrolysis. The cost of fossil energy equipped with carbon capture will likely drop by less than 10%, as the cost of fossil energy is unlikely to decrease. The cost of biomass fuel may drop 35% if technological advances can help reduce the cost of raw materials in the long term. The expected cost drop and core driving force of carbon-neutral technologies besides power industry are listed in Table 5.2.

Electricity substitution cost: Under the existing electricity supply structure in China of 2020, we estimate that the end-market cost of green electricity stands at Rmb0.58/kWh (factoring in the cost of electricity generation, peak-season power unit rescheduling, and power distribution), implying the cost of electric energy at around Rmb1,900 per tonne of standard coal equivalent. As the non-fossil energy cost keeps decreasing, the end-market cost of green electricity will likely drop to Rmb0.41/kWh in 2060, with the corresponding cost of electric energy decreasing to around Rmb1,600 per tonne of standard coal equivalent.

Hydrogen energy substitution cost: Based on the estimation of the CICC electrical equipment team, green hydrogen energy seems to have a clearer cost-reduction route than other non-power energy. The transportation and refilling cost will likely

Table 5.2 Falling costs of carbon-neutral technologies in industries other than power generation

	2020 cost per kWh	Cost reduction pathway			2030 cost per kWh	2020-30 cost reduction rate
		Economies of scale	Material substitution	Efficiency improvement		
Non-electricity technologies (Rmb/kg of standard coal equivalent)						
Electrification	1.9	√	√	√	1.6	++
Hydrogen	15.0	√	√	√	3.9	+++
Biomass ethanol	7.0				4.5	++
Natural gas and carbon capture	5.9	√	√		5.5	+
Diesel and carbon capture	7.2	√	√		6.8	+

Note Existing cost based on market prices; we use the CICC chemicals team's carbon capture cost estimate, the CICC electrical equipment's hydrogen cost estimate, and the cost of electricity substitution program is the cost of carbon-neutral technologies in the power industry. *Source* CICC Research drop by around 80% to Rmb8/kg from Rmb44/kg thanks to increased hydrogen transportation and refilling facilities and improved technologies. The cost of manufacturing hydrogen will likely drop by about 60% to Rmb9/kg from Rmb22/kg thanks to lower cost of non-fossil energy. We estimate that the cost of hydrogen energy will fall short of Rmb20/kg in 2060, meaning an energy cost at Rmb3,900 per tonne of standard coal equivalent.

Biomass-based fuel ethanol cost: According to the estimates of the CICC chemicals team, the reduction in the cost of fuel ethanol is limited, for the grain and crop demand is rather significant in China, restricting the amount of available resources. We estimate that the raw material cost will drop to Rmb2,000/tonne in the long term if technological routes utilizing less expensive raw materials (such as straw) can improve the quality of their products. In addition, we expect the cost of manufacturing fuel ethanol to drop to Rmb1,500/tonne. Overall, the cost of fuel ethanol will likely fall 35% to Rmb4,000/tonne, implying the energy cost at Rmb4,500 per tonne of standard coal equivalent.

Carbon capture cost: The CICC chemicals team estimates that the cost of carbon capture will drop to Rmb306/tonne (capture cost: Rmb195/tonne) in 2030 and Rmb262/tonne (capture cost: Rmb163/tonne) in 2060. Carbon capture technologies have advantages in integrating with the existing fossil energy system, but the downside is that such technologies always increase the energy use cost no matter what cost-reducing measures are conducted, making end-market energy use cost subject to the cost of fossil energy.

Biomass and carbon capture: Using straw and other plants as fuel, combined with carbon capture technologies, net CO_2 emission is likely to be reduced (carbon negative in other words). Positive returns can also be obtained if the cost of capturing carbon is lower than the carbon price.

5.4 "Photovoltaic + Energy Storage", Hydrogen Energy, and Carbon Capture Becoming the Main Technological Routes

5.4.1 The Main and Auxiliary Technological Routes for the Carbon Neutrality Initiative

How to choose the main technological routes for carbon neutrality in power and non-power industries? The development targets for carbon-neutral technologies in power and non-power industries as well as the feasibility of achieving these targets should be clarified on the supply side of energy, so as to lay a foundation for industries to meet the demand for energy.

The prototypes of many carbon-neutral technologies for power and non-power industries now can be utilized, and the costs of these technologies are likely to drop in the long term. The main technology selection and the turning point of technology

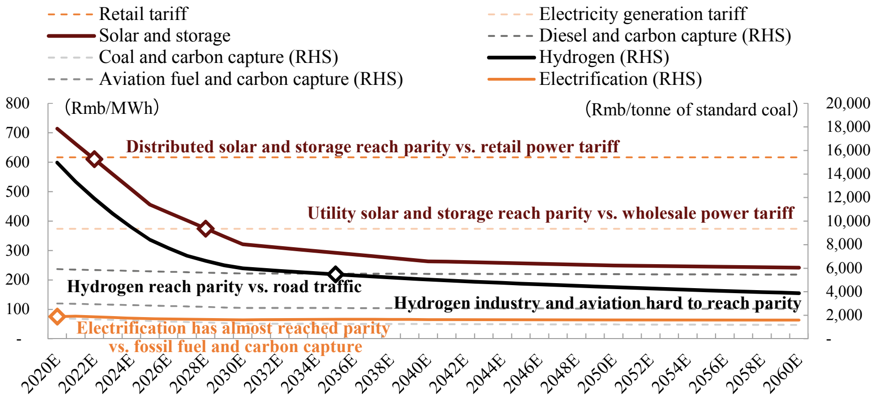


Fig. 5.4 Timing of price parity for the main carbon-neutral technological routes in power generation and other industries. *Source* Same as Fig. 5.5 & 5.7, CICC Research

penetration can be deduced through the following constraints: first, the benchmark for price parity, which traditional energy sources are selected to compare the price parity of carbon-neutral technologies and the method of comparison; second, the application scenario of carbon-neutral technologies, which refers to the compatibility of carbon neutralization technology with existing technologies and equipment; third, resource constraints, referring to the accessibility of raw materials required by carbon-neutral technologies.

Overall, carbon-neutral technologies for the power industry will achieve price parity earlier than those for non-power sectors. As shown in Fig. 5.4, the timeline we speculated for price parity is that hydropower and nuclear power have achieved price parity with coal-fired power, becoming the base energy in today's power generation hierarchy. In non-power sectors, we assess that electrification has achieved price parity with "fossil fuel + carbon capture" if we only consider the cost of energy supply. The distributed photovoltaic and energy storage may realize retail price parity with coal-fired power, and electricity consumers may spontaneously shift to clean energy in the early 14th FYP period. By the middle of the 15th FYP period, collective photovoltaic and energy storage will likely achieve on-grid tariff parity with coal-fired power projects, increasing the use of clean energy in power generation. By the end of the 16th FYP period (2030–2035), hydrogen energy will likely achieve price parity with diesel supplemented by carbon capture, and non-power toll road industry may steadily shift to clean energy. Nevertheless, it is unlikely to achieve price parity for hydrogen with "coal + carbon capture" in the industrial sector.

For the timing of implementing policies, we note that alternative-energy-based power projects that received 5–10-year government subsidies have achieved price parity with coal-fired power projects and this industry's reliance on policy tailwinds has come to an end, while energy storage and hydrogen energy projects have not achieved price parity. Policies favorable for the large-scale development of these industries are still required in the efforts to reduce technology costs and help these projects achieve price parity.

5.4.2 *The Main Technological Route for the Carbon Neutrality Initiative in the Power Industry*

In terms of the price parity of electricity generation, we notice that wind, solar, hydro, and nuclear power projects have achieved on-grid tariff parity with coal-fired power, and the cost advantages compared to fossil energy are likely to increase in the future.

The price parity timing of carbon-neutral technologies depends on when the cost of generating electricity per kWh will fall short of the benchmark price of coal-fired power. The on-grid tariffs for coal-fired power projects now average Rmb0.37/kWh in China (we assume that the cost of generating 1 kWh of electricity will remain stable as coal-fired power projects going forward), and if the cost of carbon-neutral technologies falls below the level of 0.37, the economic competitiveness of such technologies will be demonstrated.

In 2020, the cost of most carbon-neutral power is already less than that of coal-fired power. We estimate that the cost of generating 1 kWh of electricity from nuclear, photovoltaic, wind, and hydropower is 5%, 17%, 25%, and 34% lower than the cost of electricity generated through coal-fired power. Only the costs of generating 1 kWh of electricity at gas and biomass power projects remain 143% and 98% higher. By 2060, the manufacturing attributes will keep maximizing the cost advantages of wind and photovoltaic power, where the cost of the latter will be 68% lower than that of thermal power (see Fig. 5.5), becoming the cheapest clean energy source. The cost of wind, hydro, and nuclear power will be 47%, 34%, and 18% lower than the cost of thermal power respectively. The cost of gas and biomass power is constrained by limited raw materials and will stay higher than the cost of thermal power.

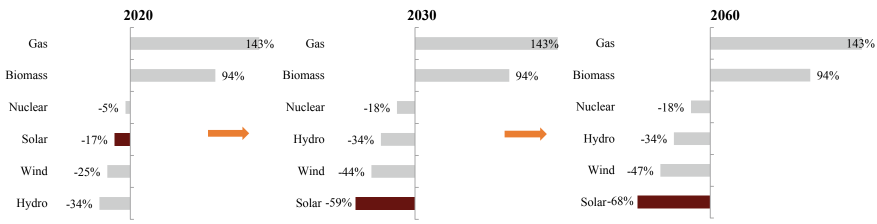


Fig. 5.5 The costs of gas, biomass, nuclear, hydro, wind, and hydropower compared to thermal power. *Notes* The current cost of generating 1 kWh of electricity is calculated using data from China Electricity Council, corporate filings of wind, solar, hydro, and nuclear power companies, and cross-checked via electricity prices released by NEA and regional power grid companies; electricity cost for 2030 is CICC estimate; gas-based power projects utilize low-carbon technologies, with carbon emissions 50% lower than the carbon emissions of traditional thermal power projects. *Source* China Electricity Council, Corporate filings, CICC Research

Conditions of price parity for grid energy storage: The cost of storing 1 kWh of electricity at electrochemical energy storage projects is unlikely to fall under the cost of pumped hydro storage projects and thermal power peak-season rescheduling projects. But the technological availability may force electrochemical energy storage to become the main technological route for the carbon neutrality initiative in the power industry.

Power grid-related energy storage costs are indispensable in electricity generation and distribution. Electricity generation from renewable energy (especially from wind power and photovoltaic projects) is less dispatchable and predictable than electricity generation from other energy sources. Improving the quality of electricity generation from these renewable-energy-based power projects requires electricity flexibility technologies. As the penetration rate of renewable energy in the power system increases, we think that inadequate flexibility in electricity will not only weigh on the balance and safety of the power system but also makes the traditional power grid model less adaptable to future power sources (and even makes existing controllable load uncontrollable). As such, the maturity of electricity flexibility technologies and lower costs of such technologies are crucial to the carbon neutrality of the power system.

The timing of price parity for carbon-neutral technologies utilized in power grid-related energy storage: Electrochemical energy storage and pumped hydro storage are not very likely to reach price parity with thermal power peak-season rescheduling projects (measured by the electricity cost per kWh). Given the existing technological routes, we think the electricity charging cost of electrochemical energy storage projects and pumped hydro storage projects per kWh is unlikely to fall short of the electricity charging cost of thermal power peak-season rescheduling projects (Rmb0.14/kWh).

Electrochemical energy storage will likely become the main carbon-neutral technology for power grid-related energy storage, due to restraints from application scenarios and the potential of project development. Given the life cycle of thermal power units, we think that from 2030 the phase-out of coal-fired power units that are less than 0.6mn kW will be intensive (such units have been transformed so as to become more flexible, and they can improve power grids' capabilities of receiving renewable energy), and that most thermal power units in the power system will be more than 1mn kW (such units have high parameters and low emissions, and are less flexible) as well as combined heat and power (CHP) units (electricity generation from such units is subject to heat supply conditions, and they are less flexible). As a result, the energy storage competence of thermal power peak-season rescheduling projects will likely weaken from 2030. In addition, the pumped hydro storage capacity that can be developed in China is around 120GW, according to China Renewable Energy Engineering Institute. We think that as the penetration rate of wind and photovoltaic power exceeds 30%, the existing energy storage capacity of the power system will become insufficient to store electricity generated by renewable-energy-based power projects and electrochemical energy storage may become the main technological route for the carbon neutrality initiative in the power industry.

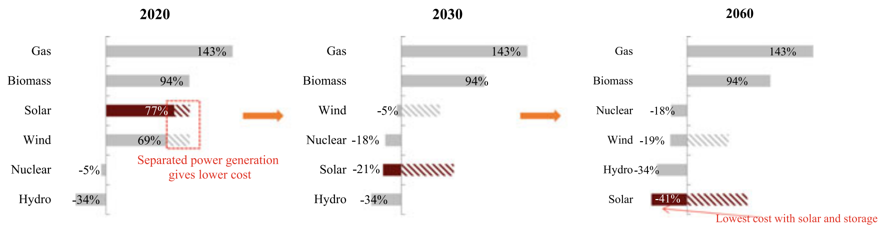


Fig. 5.6 Comparing the electricity generation and energy storage cost of gas, biomass, nuclear, hydro, wind, and solar power to thermal power projects (assuming an energy storage ratio of 50%). *Note* The current cost of generating and storing 1 kWh of electricity is calculated from data of China Electricity Council, corporate filings of wind, solar, hydro, and nuclear power companies, and cross-checked via electricity prices released by NEA and regional power grid companies; electricity cost for 2030 is CICC estimate; gas-based power projects utilize low-carbon technologies, with carbon emissions 50% lower than the carbon emissions of traditional thermal power projects. *Source* CICC Research

Factoring in electricity generation and energy storage, we think that photovoltaic and electrochemical energy storage projects will achieve on-grid tariff parity with coal-fired power projects in 2028, and the cost of photovoltaic and electrochemical energy storage projects will be slightly higher than the cost of hydro and nuclear power projects in 2060. We believe photochemical energy storage technologies will play an important role in the carbon neutrality initiative of the power industry, given the flexibility of these technologies and the availability of related resources.

The timing of the price parity of carbon-neutral technologies in the power sector depends on when the cost of electricity generation and storage will drop below the on-grid tariff for coal-fired power. As shown in Fig. 5.6, the costs of electricity generation and energy storage of photovoltaic and wind power are 77% and 69% higher than the cost of thermal power, assuming the energy storage ratio to be 50%. Their costs are also higher than the costs of nuclear and hydropower that are capable of self-adjusting and relieving energy storage problem of the power grids. We expect the cost of photovoltaic and energy storage to be on par with the average on-grid tariff for coal-fired power (Rmb0.37/kWh) by 2028. As thermal power is phased-out subsequently, photovoltaic will gradually replace thermal power to avoid cost rebounds and the cost of photovoltaic will be 41% lower than that of thermal power by 2060. In addition, nuclear and hydro power projects do not incur energy storage problems in power grids. We estimate that the costs of nuclear and hydro power will be 18% and 34% lower than the cost of thermal power by 2060, largely on par with the cost of photovoltaic power.

The places where energy technologies are utilized and the potential of developing power projects: Photovoltaic projects can be developed in a rather flexible way and photovoltaic resources are ample (see Fig. 5.7). As such, we believe photovoltaic technology will become the main technological route for carbon neutrality in the power industry, even if it does not have an absolute cost advantage compared with nuclear and hydropower. We think hydro, nuclear and wind power technologies will become the auxiliary technological routes for a multi-energy complementary system.

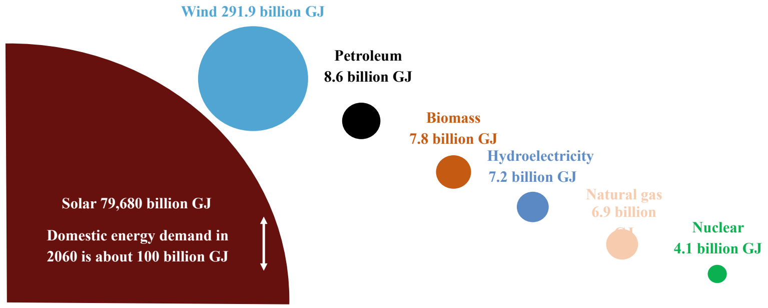


Fig. 5.7 Carbon-neutral resources for electricity projects in China. *Note* The sizes of these bubbles represent the volume of carbon-neutral resources that are available in China; we show only 25% of the bubble for photovoltaic resources, as the volume of this energy source is markedly higher than the volume of other resources. *Source* China Meteorological Administration, National Bureau of Statistics of China, CICC Research

Application scenarios: Distributed photovoltaic and energy storage projects can help reduce the cost of power distribution. We expect such projects to achieve price parity more easily than centralized photovoltaic and energy storage projects.

The exploitation boundaries: The volume of photovoltaic resources is higher than that of other clean energy, which makes it possible to meet the increased energy demand.

5.4.2.1 Assessment of Practical Potential for Carbon-Neutral Technologies in Non-Power Industries

The concept of price parity is not applicable to carbon capture alone. Given estimates on technology-enabled drops in energy costs per tonne of standard coal equivalent, we think that electrification has largely achieved price parity with the fossil energy and carbon capture technological route, and hydrogen energy may reach price parity in the land transportation industry by 2035. However, biomass fuel and hydrogen energy are not very likely to achieve price parity in the manufacturing and aviation industries.

Electrification: According to the estimates of CICC industry teams, the cost of electrification technologies stands at Rmb1,900 per tonne of standard coal equivalent, lower than the cost of natural gas and carbon capture technologies (around Rmb3,600 per tonne of standard coal equivalent), diesel and carbon capture technologies (around Rmb6,000 per tonne of standard coal equivalent), and on par with the cost of coal and carbon capture technologies (around Rmb1,700 per tonne of standard coal equivalent). Thanks to lower clean energy costs, the cost of electrification technologies may continue to drop and maintain its economic advantage.

Hydrogen energy: Hydrogen energy is expected to achieve price parity with diesel and carbon capture technologies in the ground transportation industry by the end of the 16th FYP period, with the cost of hydrogen energy coming in at around

Rmb5,500 per tonne of standard coal equivalent according to CICC's estimates. However, price parity with coal and carbon capture technologies (Rmb1,200 per tonne of standard coal equivalent) in the manufacturing industries and with jet fuel and carbon capture technologies (Rmb2,500 per tonne of standard coal equivalent) for hydrogen is relatively hard to achieve by 2060.

Biomass-based fuel ethanol: The CICC agriculture team estimates that the price of biomass-based fuel ethanol will drop to Rmb4,500 per tonne of standard coal equivalent by 2060 from nearly Rmb7,000 per tonne of standard coal equivalent in 2021e, higher than the cost of jet fuel and carbon capture technologies (Rmb2,500 per tonne of standard coal equivalent) and thus cannot realize price parity.

If higher photovoltaic efficiency and lower electricity cost can reduce the end-market hydrogen price to Rmb12.5/kg (and Rmb5.8/kg for manufacturing industries, lower than our base-case hydrogen price forecast of Rmb18.8/kg for 2060), hydrogen will achieve price parity in the aviation industry (and the manufacturing industries). The cost of photovoltaic power should drop to Rmb0.02/kWh or even Rmb0.00/kWh to enable price parity of hydrogen in the aviation industry, lower than our base-case photovoltaic power price forecast of Rmb0.12/kWh for 2060. This shows that the large-scale use of hydrogen in the aviation and manufacturing industries remains difficult. In addition to hydrogen manufacturing costs, hydrogen storage and transportation costs should also decline. Otherwise, end-market users are more likely to utilize carbon capture technologies to achieve carbon neutrality.

Comparisons among costs of traditional energy, electrification, hydrogen energy, and biomass fuel are shown in Fig. 5.8.

In addition to the cost reduction of energy technologies, the penetration rate of technologies is also important. Exploitations in application scenarios and boundaries should expand from the application side.

Application scenarios: Hydrogen energy substitution is incompatible with current mainstream technologies. Carbon capture technologies can only be utilized in fixed manufacturing facilities.

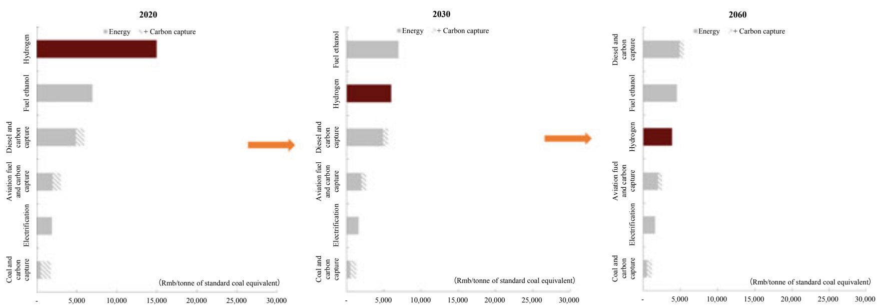


Fig. 5.8 Comparing the cost of traditional energy and the costs of electrification, hydrogen energy, and biomass fuel. *Note* Existing cost based on market prices; we use the CICC chemicals team's carbon capture cost estimate, the CICC electrical equipment's hydrogen cost estimate, and the cost of electricity substitution program is the cost of carbon-neutral technologies in the power industry. *Source* CICC Research

Application boundaries: Obtaining the raw materials for manufacturing biomass fuels faces constraints.

5.5 Policy Suggestions: Enhancing Technology R&D Protection; Supporting the Industrialization of New Technologies

Policies should give support to energy forms that are cleaner and more efficient, and create an open environment for various technologies to compete, leaving room for the market to decide the main direction for technology development. In formulating policies, the common development direction of energy technologies should be clarified. For the development of low-carbon clean energy, policies should put forward specific requirements (such as support for zero emissions and advanced technologies that have higher efficiency and the potential of "surpassing" the existing more advanced technologies) so as to improve China's advantage in top-level design. Judging from past experience, we think that China should allow multiple technological routes to co-exist and compete. Market should have the final say, with end-market users making choices based on the advances in and the costs of energy technologies. Patent protection is crucial to the shift from importing technologies to developing proprietary technologies. Since the protection of intellectual property has not been emphasized in China, some Chinese companies were forced to locate their R&D centers overseas, which bodes will for the development of alternative energy technologies in China. Policies that support patent protection should be intensified and should encourage patent applications for research outputs, as well as support for enterprises that keep investing in technological development, so as to improve energy technologies.

Power sector should focus on propelling the use of non-fossil energy technologies. Emphasis should be put on the large-scale use of energy storage and power grid-related technologies. As the proportion of non-fossil energy rises, whether energy storage technologies can keep abreast of such energy holds the key. On the one hand, energy storage technologies are slightly different from electric vehicle (EV) batteries. Such technologies require lower energy density, more cycles, and attach greater importance on safety. It will be difficult to promote energy storage technology development without sufficient market demand. On the other hand, the structure of electrical grids will turn from the previous "uncontrollable load and controllable electricity source" structure to "uncontrollable load and uncontrollable electricity source" structure, suggesting that not only policies that clarify costs are required, technological applications that reduce standby redundancy in power grids are also indispensable to increase efficiency and optimize the parity between supply and demand. Policies should put emphasis on propelling pilot projects for smart power grid technologies, showing development directions of such technologies. Non-power sectors should also support the industrialization of new technologies and introduce incentive policies at the appropriate time. Only technological advancements could stimulate the end-market usage in non-power sectors as the costs remain relatively high. Based on historical experience, we estimate that it takes 20 years for a technology to attain the level of industrialization, and takes the same amount of time to achieve maturity in the application. Multiple technologies, including hydrogen energy, carbon capture, and biomass technologies, among others, are now utilized in non-power industries. However, hydrogen energy technologies are not compatible with the fossil energy technologies utilized in non-power industries. As such, policies that support the development of hydrogen energy-related technologies are necessary.

The Frontrunner Photovoltaic program is a replicable success and can help industrialize new technologies. Government executes pilot projects and implement preferential policies that provide subsidies and reduce taxation to facilitate new technologies to overcome barriers. The Frontrunner Photovoltaic program has provided an arena for high-efficient products and advanced technologies in the photovoltaic industry. In the meantime, projects under this program enjoy a series of favorable policies that pertain to land parcels and network connections. These favorable policies can reduce non-technological costs to the fullest, allowing projects to focus on cutting photovoltaic power cost and enhancing electricity generation efficiency.

When should policy support be provided? Judging from experience in other countries and subsidy policies launched at the preliminary development stage for renewable energy in China, we think that governments can roll out favorable policies for non-power technologies (such as hydrogen and carbon capture technologies) when the costs of such technologies are 200% higher than the cost of traditional energy.

Reviewing Germany and Japan's experiences in rolling out photovoltaic power subsidies in 2000 and 2012, the prices of photovoltaic power were 163% and 250% higher than the on-grid electricity prices. In addition, China began to provide subsidies for onshore wind power, photovoltaic power, and offshore wind power in 2009, 2013, and 2014 respectively, as the prices of onshore wind power, photovoltaic power, and offshore wind power were 45%–68%, 120%–254%, and 89% higher than the on-grid tariff for coal-fired power projects. According to these cases, it seems to be a general pattern that countries typically provide photovoltaic power subsidies when the price of photovoltaic power is around 200% higher than the on-grid tariff. The cost of photovoltaic power continues to drop following the implementation of subsidy policies, and photovoltaic power can ultimately achieve price parity with traditional power sources. As a result, favorable policies can be rolled out for hydrogen energy and carbon capture technologies when the costs of these technologies are nearly 200% higher than the cost of traditional energy. In our opinion, these policy tailwinds will facilitate the development of hydrogen energy and carbon capture technologies, and help reduce the costs of these technologies.

5.5.1 Technologies that May Develop More Rapidly Than Expected

If the cost of carbon capture reduces and brings the economic advantage of this technology, the demand for developing hydrogen technologies may shrink. Carbon-neutral technologies used in non-power industries are mainly carbon capture, hydrogen, and biomass technologies, each having different pros and cons. Carbon capture technologies have gained the advantage of being compatible with existing energy technologies, for carbon capture devices can be attached to the tail ends of existing facilities to reduce CO_2 emissions, which is more convenient than hydrogen technologies. But reducing the cost of storing the carbon captured from energy projects remains difficult, and the overall zero-carbon cost (fossil energy + carbon capture) is subject to fossil energy prices. If carbon capture technologies can make a new breakthrough in application, the cost of carbon capture technologies may drop markedly, which means carbon neutrality will likely come earlier than expected as these technologies are compatible with existing energy and manufacturing systems.

The use of nuclear power may increase markedly if fourth-generation technologies can notably improve the safety of nuclear power projects, which may further affect the power structure. Nuclear power is of great importance as one of the cleanest and highly efficient base-load powers. However, the development of the nuclear power industry has faced headwinds, e.g., nuclear power stations must be built far from residential areas. Workplace safety is the top priority in the nuclear power industry and the focus of nuclear technological development. Hence, if the design of nuclear power stations can secure the safety of these projects, the scale of application will increase rapidly. In the long term, nuclear energy is still an energy source with the highest energy density available, and solar energy also comes from the reaction of nuclear fusion, suggesting the sustainability of nuclear power. We believe the use of nuclear fusion technologies will start a new technological revolution in the energy industry once controllable nuclear fusion is achieved.

Photovoltaic efficiency is also likely to exceed our estimate. In the previous section, we only considered the perovskite technology (the photoelectric conversion efficiency of this technology can reach 30% thanks to the current technological route), and we did not consider the use of condensation and multi-junction technologies. It is likely for the photoelectric conversion efficiency of photovoltaic technologies to exceed 40% in the long term, given continuous technological advancements. If the costs of photovoltaic technologies continue to drop, more applications and energy usages can be expected.

5.5.2 Technologies that May Develop More Slowly Than Expected

The development of energy storage technologies may proceed more slowly than we expect. Connecting voluminous renewable-energy-based power projects to the existing electricity system in China may make regional power grids less balanced, due to the fluctuation in instantaneous electricity generation, daily curves, and seasonal resources of renewable-energy-based power projects. The penetration rates of renewable-energy-based power projects (such as wind and solar power projects) are high in Australia, the UK, and California. Their power systems in recent years experienced balance and safety issues under extreme conditions, requiring stronger instantaneous balancing capabilities. In the short term, enhancing the flexibility of the electricity system is crucial to increasing the use of non-fossil energy. Electricity systems could encourage thermal power peak-season rescheduling and pumped energy storage to improve scheduling at regional and national levels. However, problems related to electricity demand forecasts and electricity price signals need to be resolved.

The development of hydrogen energy technologies may proceed more slowly than expected. Hydrogen energy technologies are not compatible with the existing technologies. Technologies should improve notably so as to enable industries to shift from traditional energies to hydrogen energy. In the air transportation industry, countries have accelerated the R&D of hydrogen-powered airplanes to resolve related problems. The mixed combustion of hydrogen in aero-engines requires technological breakthroughs, and hydrogen storage has imposed higher requirements on the design of fuel tanks. In September 2020, Airbus released three concepts for zero-emission hydrogen-powered commercial aircraft slated to enter service in 2035. China's carbon neutrality initiative may be affected, if the use of hydrogen technologies proceeds more slowly than expected (or such technologies cannot be utilized).

Chapter 6
Green Energy: A New Chapter in China

Abstract This chapter discusses how China can cut energy-related emissions which account for nearly 90% total. The sticking point is that apart from having a large base, China's sustained economic growth will boost its overall energy consumption demand as its GDP per capita catches up with developed countries, making curbing energy-related emissions a tougher task. After calculating the green premium, we believe green electricity and electrification have become economically feasible and technologically available. However, non-electric applications, including hydrogen power require further technological upgrades and cost reductions to become economically viable. Given the changes in energy consumption habits and the structural changes necessary to achieve carbon neutrality in China, we believe there needs to be policy guidance and society-wide support with regard to cutting emissions. We expect the government to accelerate the development of immature technologies such as hydrogen power, after their green premiums fall to certain levels. According to the estimation by CICC research teams, 70% of the energy usage will be provided by green electricity and 8% by green hydrogen. The rest of the 22% will be neutralized using carbon capture to achieve carbon neutrality in terms of energy. Realizing this goal requires effort from both the supply and demand sides.

6.1 Overview of China's Current Energy Structure

6.1.1 Energy Sector Produces Nearly 90% of Carbon Emissions in China; Building Green Energy Supply System is Top Priority

At the current stage, China's energy supply is still dominated by coal, with petroleum, natural gas, and non-fossil fuels providing the rest. Reducing carbon emission and tackling climate change have become the common task of the international community, and according to UN Environment Programme's *Emissions Gap Report 2019* of the total emission, China is the largest carbon dioxide emitter and contributed

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_6

over 25% of global emissions in 2018. China's promise to achieve carbon neutrality in 2060 will facilitate its integration into the international community and help the country achieve its dual circulation model, creating synergies between domestic and overseas markets.

We believe greater efforts toward reaching "low-carbon" and "zero-emissions" are key to achieving carbon neutrality in the energy sector.

6.1.2 Total Energy Demand May Increase Under Steady Economic Growth Despite Decline in Energy Consumption Per Unit of GDP

Official data shows that China's GDP per capita is only one-sixth to one-third of that of developed countries, pointing to substantial growth potential. CICC macro team expects that in 2020Q1 China's GDP to grow 4.2%, 3.0%, 2.5% and 2.0% in 2030, 2040, 2050 and 2060 respectively. China's GDP per capita rose to US$10,276 in 2019 (more than doubling from US$4,628 in 2010, see Fig. 6.1), which means it not only met twice as much the US$10,000 GDP per capita national target but has also successfully built a moderately prosperous society in 2020 in all respects (initiated by the 18th CPC National Congress). Looking ahead, given China's plan to basically achieve modernization by 2035 and national rejuvenation by 2050, we expect its GDP per capita to rise to US$41,105 in 2060, reaching current levels in Japan and Germany.

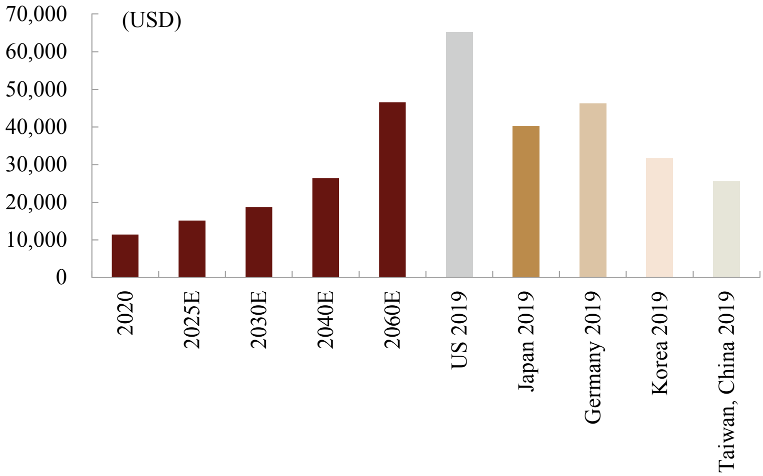


Fig. 6.1 Comparison of per capita GDP (China vs. other countries and regions). *Source* NBS, government websites, CICC Research

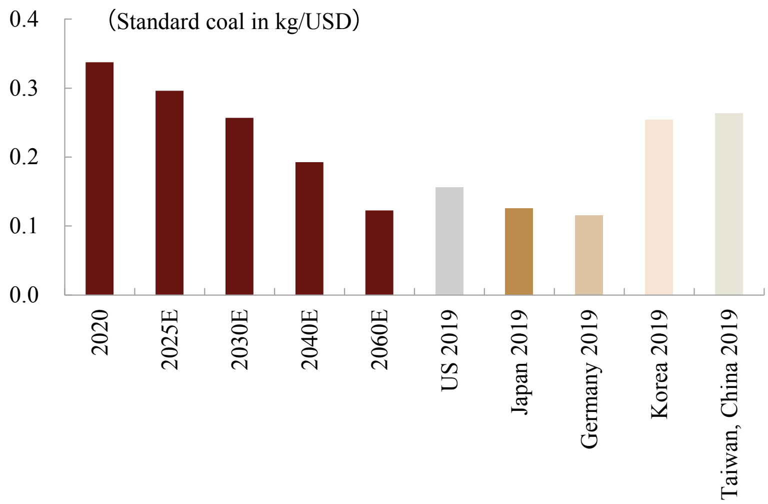


Fig. 6.2 Comparison of energy consumption per GDP (China vs. foreign countries and regions). *Source* National Energy Administration, NBS, government websites, CICC Research

China's current energy consumption per unit of GDP is still at a high level and to be lowered by energy restructuring and conservation. According to official data, China's energy consumption per unit of GDP stood at 0.328kg of standard coal/USD, which is higher than developed countries' 0.116–0.264kg of standard coal/USD (Fig. 6.2). With improvements in the country's economic structure and its greater efforts to curb energy consumption, we expect its energy consumption per GDP to drop 63% from the current level to 0.123kg of standard coal/USD in 2060, lower than current levels in the US and Japan.

However, even considering the possible decline in energy consumption per capita, we expect China's economic growth to boost total energy consumption to 6.73bnt of standard coal in 2060 (+38% compared to the current level, see Fig. 6.3). We estimate that China's total energy consumption will likely rise to 5.76, 6.36 and 6.73bnt of standard coal in 2025, 2035 and 2060 respectively, with continuous YoY growth. As the proportion of tertiary industries with lower energy consumption per unit of GDP rising, we expect China's energy consumption growth to be slower and its CAGR to fall from 3.3% in 2021–2025 to 1.0% in 2025–2035 and 0.2% in 2035–2060.

6.1.3 Carbon Emissions Reduction is Difficult to Achieve Under Current Energy Structure; The Country Needs Stronger Top-Down Planning and Policy Support

As the world's largest emitter, China confronts multiple difficulties in lowering carbon emissions. To achieve carbon neutrality, China's energy structure should be

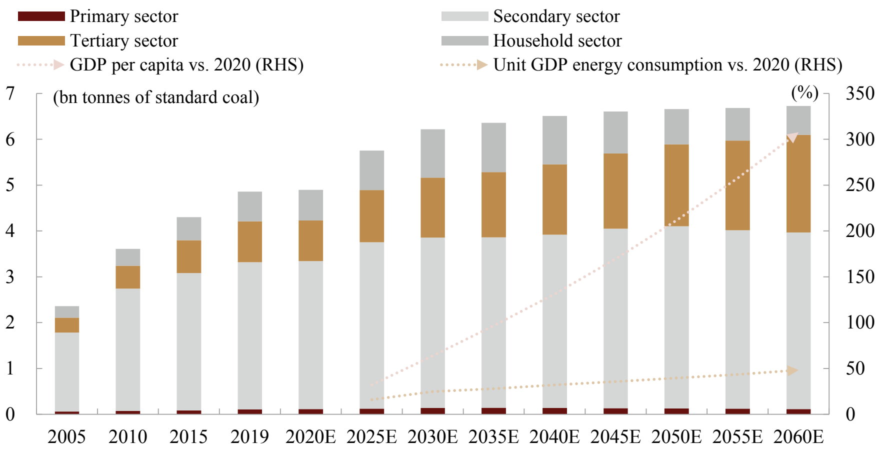


Fig. 6.3 Total energy consumption forecast. *Source* NBS, CICC Research

cleaner, safer and more economically feasible. With increasing energy demand and restrictions on carbon emissions, the goal to achieve carbon neutrality will be more challenging for China, which requires stronger policy support. It will also accelerate China's energy transformation, benefiting economic growth eventually. Setting the goal of carbon neutrality marks China's step toward energy reform, and will make the country's energy structure cleaner, safer and more economically favorable in 2060. The energy structure in China is displayed in Fig. 6.4.

To reach carbon neutrality in the energy industry, China should make electric power generated by non-fossil fuels the major energy source in its future zero-emission system and accelerate the rate of electrification. The government may also

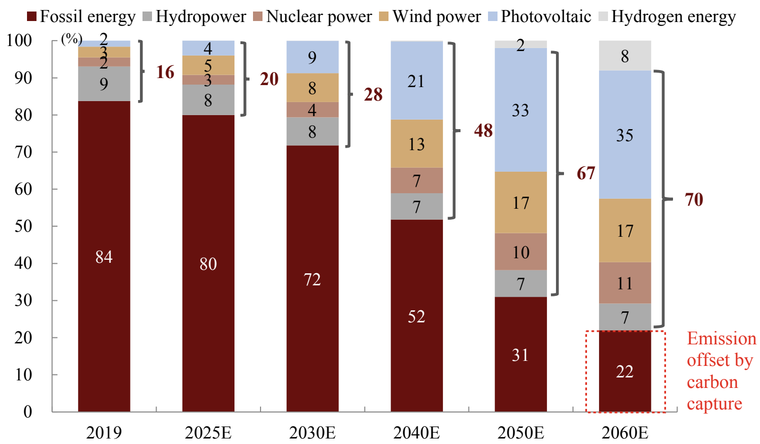


Fig. 6.4 China's energy structure (2019–2060). *Source* BP Energy, CICC Research

promote the development of new non-electric technologies such as hydrogen energy and carbon capture technology. Based on estimates by various CICC sector research teams, we expect the energy sector to achieve carbon neutrality by 2060 through raising clean electricity's share of total energy supply to 70%, green hydrogen's share to 8%, and the share of other energy sources supported by carbon capture technologies to 22%. Attaining this goal requires efforts from both the supply and demand sides. On the supply side, power generation should be cleaner, while on the demand side, government should encourage the deployment of other renewable technologies.

6.2 Start from More Feasible Methods to Achieve Energy Transition Through More Economical Ways

How can the energy sector contribute to carbon neutrality? Given that China should achieve green electricity first, then clean non-electric energy, raising the electrification rate should help accelerate emission cuts.

Energy transition lays the foundation for carbon neutrality. We think it will be difficult for the cement, steel and electrolytic aluminum industries to completely internalize the cost of achieving carbon neutrality given their current energy structure, technology level and costs. In contrast, the chemical industry can internalize the costs but would have to sacrifice profitability. The costs of carbon neutrality are more affordable for manufacturing industries only.

Among all the paths to achieve carbon neutrality, why do we think green electricity should come first, and then non-electric applications?

Green Electricity: We believe replacing thermal power with clean energies can effectively lower carbon emissions from power generation. We estimate the power industry's green premium will likely turn negative by 2030, ahead of other sectors. A zero-emission electric power generation system is almost economically feasible today, and its green premiums may turn negative in 10 years with lower grid costs.

Clean Non-electric Energy: Acceleration of electrification rate, energy conservation, carbon emissions reduction, and new technology applications including hydrogen power and carbon capture, rely on technology breakthroughs and policy support. Green premiums for hydrogen power and carbon capture are likely to remain high in the near future and China should focus on electrification since it is more economically feasible. We estimate China's electrification rate may rise to 70% by 2060, and the remaining 30% of energy demand could be met by hydrogen power and carbon capture technology. These two technologies have different applications. According to estimates by various sector teams in CICC Research, we believe the penetration rate of carbon capture will likely be higher in 2060, especially in the commodities sector. In contrast, hydrogen power will likely be applied more in the transportation and chemical sectors. Our estimation of the green premium in the non-power sector is 175% in 2021. If costs of fossil fuels stay unchanged but those of carbon capture and hydrogen power decline, green premiums in the non-power sector may fall to 57% in 2030 and 14% in 2060. While they may fall, we believe they will stay above 0%. This means that the total cost of non-electric power consumption will likely rise to achieve carbon neutrality.

As shown in Table 6.1, green electricity and clean non-electric applications combined present the best solution for carbon neutrality.

6.3 Lowering Costs to Raise Non-fossil Fuels' Proportion in Power Generation

6.3.1 Calculation of Green Premiums in Power Sector

Costs in the power sector mainly come from three key variables: power generation, absorption, and electricity transmission and distribution. For power generation, we look at the structure of power sources and their costs per kilowatt-hour (kWh) of electricity generation. For absorption, the proportion of flexible power resources including peak-load regulation supported by thermal power units, pumped-storage hydropower, electrochemistry energy storage, and their costs per kWh generation. Moreover, we expect the penetration rate growth of wind and photovoltaic (PV) power to boost demand for absorption, pushing up the proportion of absorption volume in power generation. Thus, compared with the base scenario, achieving carbon neutrality will change power generation costs and boost demand for absorption. We assume the costs of electricity transmission and distribution remain unchanged. We expect green premiums in China's power industry to turn negative by 2030 (Fig. 6.5).

2021: Compared to the basic scenario, in the carbon neutrality scenario, the green premium is 6% for power generation, and 3,600% for absorption. If the cost of electricity transmission and distribution remain unchanged, the green premium in the power sector would be 17%.

2030 forecast: Compared with the base scenario, power generation sees a green premium of −17% in the carbon neutrality scenario and around 5 times the size of green premiums in absorption. The green premium in the power sector may thus turn to −4% in 2030.

The CICC alternative energy and electrical equipment team expects all thermal power units to retire in 2051. By then, China's energy source mix should include hydro, nuclear, wind and solar energies, achieving zero-emissions.

Table 6.1 Green electricity and clean non-electric applications combined present the best solution for carbon neutrality

	Green electricity + Clean non-electric energy	Energy saving and emission reduction only	Carbon sink only
Impact on economic development	Emerging manufacturing drives industrial upgrading and economic development	Suppress the growth of energy demand and economic development	Massive forest land required to achieve carbon neutrality, thus affecting land resources
Conclusion	*Positive*	*Negative*	*Negative*
Impact on energy security	Renewable manufacture industry will help China get rid of energy import and become an energy exporter	Still rely on energy import	Still rely on energy import
Conclusion	*Positive*	*Neutral*	*Neutral*
Impact on carbon emissions	Reach carbon neutrality	Carbon peak can be reached, while carbon neutrality cannot be reached	Reach carbon neutrality
Conclusion	*Positive*	*Positive*	*Positive*
Cost	The decrease of the cost of Photovoltaic power generation and storage is expected to drive down the cost of energy use in the whole society, while hydrogen energy and carbon capture slightly raise the cost of energy use	The carbon tax collection process as a driving factor will bring additional economic losses	High cost of greening
Conclusion	*Positive*	*Negative*	*Negative*
Comprehensive conclusion	**Best solution**		

Source CICC research

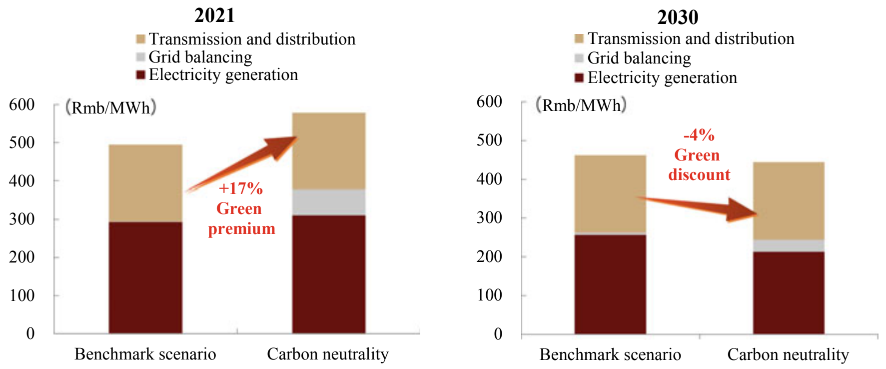


Fig. 6.5 The green premium in the power industry in 2021 and 2023 (the CICC alternative energy and electrical equipment team expects China's power system to achieve carbon neutrality in 2051). *Note* Our estimation of costs per kWh power generation is based on data from China Electricity Council, energy companies, GGII and LEK Consulting; we cross check it with electricity prices released by National Energy Administration and regional power grids. *Source* China Electricity Council, corporate filings, GGII, LEK, CICC Research

6.3.2 *Power Generation: Non-fossil Energy's Lower Costs Per kWh Fuels Transition to Cleaner Energy Mix*

The costs per kWh electricity generation of hydropower and wind power are already lower than that of thermal power in 2021 (see Fig. 6.6 left side). But the nationwide average costs per kWh of nuclear power and PV power are still slightly higher than for thermal power. Thermal, hydro, wind, nuclear and PV power account for 68%, 16%, 7%, 5% and 4% of total generation, respectively. We estimate average power generation cost in China is Rmb293/kWh. In the carbon neutrality scenario, if the

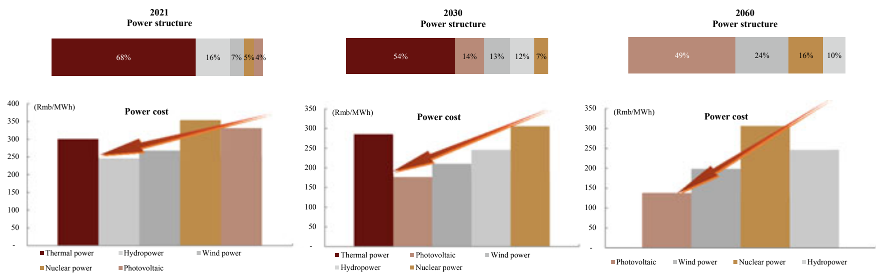


Fig. 6.6 Breakdown of costs per kWh power generation (generation costs determine proportion). *Note* Our calculation of costs per kWh power generation is based on data from the China Electricity Council, energy companies, GGII and LEK Consulting; we cross check it with electricity prices released by the National Energy Administration and regional power grids. *Source* China Electricity Council, corporate filings, GGII, LEK, CICC Research

power system achieves zero-emissions by 2060, average green electricity costs will rise to Rmb311/kWh, with a green premium of 6%.

In 2030, we estimate the costs of PV and wind power may be lower than that of hydro and nuclear power, and the cost of clean energy lower than thermal power. According to the CICC alternative energy and electrical equipment team's power resource mix forecast (thermal, PV, wind, hydro and nuclear power contribute 54%, 14%, 13%, 12% and 7% of total power generated in 2030), we estimate China's power generation cost would then be Rmb257/kWh in 2030. In the carbon neutrality scenario, the cost of green electricity is Rmb213/kWh under a zero-emission structure. And as the costs of wind, hydro, nuclear and solar power are lower than thermal power, the green premium of power generation would turn to −17% by 2030 (see Fig. 6.6 middle).

As the costs of clean power are lower than thermal power after 2030 and thermal power units would gradually retire, the CICC alternative energy and electrical equipment team expects emissions of the power generation system would fall without external help and would see zero emissions by 2060 (see Fig. 6.6 right side).

6.3.3 Absorption: Complementary Multi-energy System Minimizes Absorption Costs

We believe that increasing the new energy penetration rate will drive up absorption costs. Given global experiences, we notice that absorption costs (calculated by amortized ancillary power system service costs of per kWh power generation) will likely rise notably with wind power and PV power's penetration rate growth in the power system. By then, absorption can represent 10%–20% of total costs in different power markets, hence extending the time for green premiums to fall to zero. We expect a multi-energy complementary power system would minimize absorption costs. Breakdown of per kWh absorption costs is displayed in Fig. 6.7.

As peak-load regulation supported by thermal power can minimize absorption costs, we don't think thermal power will be abandoned in the near future.

A multi-energy complementary system effectively lowers absorption demand and costs as well as green premiums of power generation and power grid (see Fig. 6.8).

If electrochemistry energy storage achieves technology breakthroughs and much lower prices with policy support, it may notably lower absorption costs and help China achieve green electricity earlier.

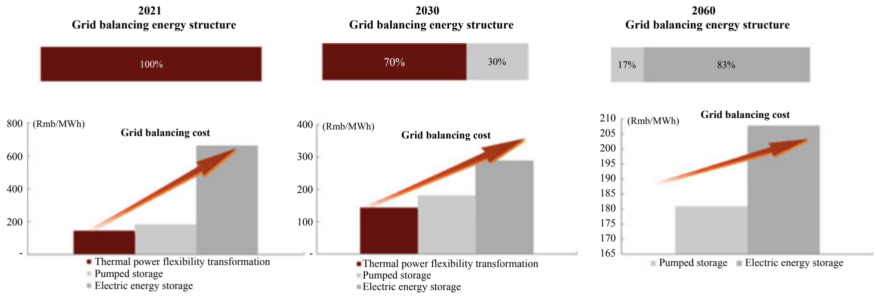


Fig. 6.7 Breakdown of per kWh absorption costs (costs determine structure). *Source* Our estimation of costs per kWh power generation is based on filings, and data from GGII and LEK Consulting, we cross check it with the electricity prices released by National Energy Administration and regional power grids

6.4 Non-power Sector: Electrification, Hydrogen Power and Carbon Capture Fuel Energy Transition

6.4.1 China's Electrification Rate Will Likely Reach 70%; The Remaining 30% Demand Requires Non-electric Power and Other Energy Resources Supported by New Technologies to Achieve Carbon Neutrality

Looking into sub-sectors, black metal (iron and steel), transportation and warehousing (AFV, railway) and civil sectors (collective heating) have more room for growth in electrification (Fig. 6.9). Based on our estimation, non-electric power consumption accounted for 54% of China's energy consumption in 2019. However, some energy cannot be replaced by electric power given higher requirements for energy density and long-term storage, and the fact that it cannot transform to electric power. Based on the estimation from the CICC research team of the future form of energy, together we see the electrification rate in 2060 may reach 70%, with other energy sources meeting the remaining 30% demand.

6.4.2 Non-power Sector: Hydrogen Power and Carbon Capture is Feasible Technology Solution to Carbon Neutrality

Achieving carbon neutrality in the non-power sector is the last step towards overall carbon neutrality. We think carbon capture and hydrogen power are two feasible technologies at the current stage. Carbon capture's penetration rate will likely be higher, especially in commodities sectors. In contrast, hydrogen power would be

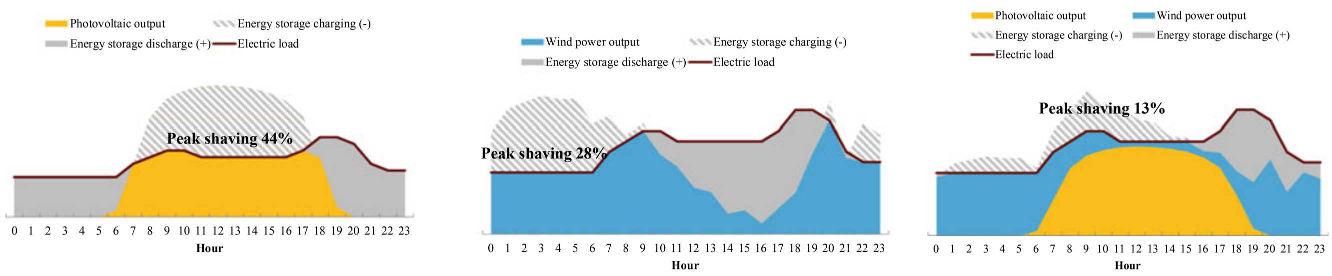


Fig. 6.8 Wind and solar power can compensate each other; multi-energy complementary system lowers demand for energy storage. *Source* CICC Research

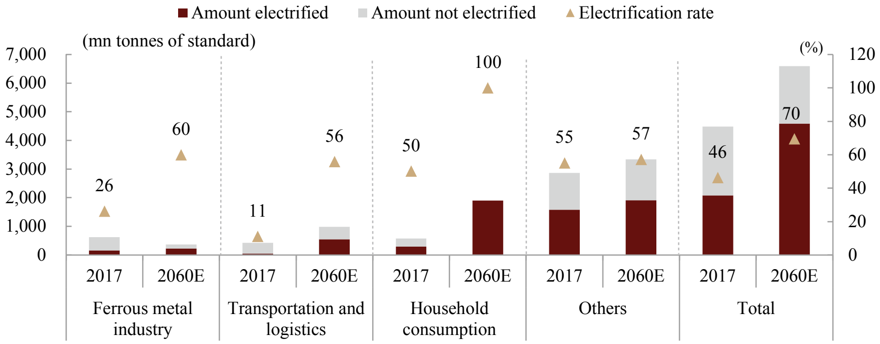


Fig. 6.9 Electrification rate forecast for major energy consumption sectors (2017 vs. 2060). *Source* National Energy Administration, CICC Research

applied in the transportation and chemical industries. The two technologies have different application scenarios but should develop at the same pace.

Carbon capture is more suitable for industrial sectors. Electrification is limited in some industrial sectors, including chemistry, metal and non-metal smelting, paper-making as they require fuel burning which cannot be substituted by the electricity. Adopting hydrogen power would require a new production process. In contrast, we believe carbon capture technology is more convenient in these instances. It can integrate with existing technologies and requires some extra equipment.

Hydrogen power is more suitable for transportation and chemical industries. In some sectors, it is the energy consumption model rather than costs that limit electrification. For example, electric power cannot support long-term transport such as aviation and shipping. But hydrogen power's high energy density makes it the most feasible to replace the fossil energy.

6.4.3 Other Energy Resources Adopted Carbon Capture and Hydrogen Power to Meet 22% and 8% Energy Demand in 2060

6.4.3.1 Hydrogen Power

Given the carbon emission forecasts for major emissions contributors, we expect hydrogen power consumption volume will rise to 110mnt (540mnt of standard coal) and 130mnt (650mnt of standard coal) in 2060 in neutral and optimistic scenarios under carbon neutrality, fulfilling 8%–10% of energy demand in 2060.

Transportation: With hydrogen power's high mass-energy density and low volumetric energy density, hydrogen fuel cells can be used in long-distance transport scenarios without strict space requirements, such as highways, heavy-duty trucks, and aviation. Its fast charging feature also facilitates commercialization. In the optimistic scenario, the CICC transportation team expects 100% hydrogen-fueled heavy-duty trucks and the use of hydrogen power in aviation and shipping sectors.

Chemical industry: We expect to see hydrogen power in synthetic ammonia and methanol production. We think synthetic ammonia production can transform from alkaline electrolysis cells (AEC) to proton exchange membrane electrolysis (PEM) and finally to solid oxide electrolysis cells (SOEC), achieving 100% replacement of fossil fuels by hydrogen power. Methanol production will likely see similar transitions.

Manufacturing: We expect manufacturing subsectors to raise their concentration ratios via merger and acquisition, as well as market competition. As the total number of players reduces, advanced processes can be more widely applied.

6.4.3.2 Carbon Capture

Given our technology path forecast, some raw materials or fuels cannot be replaced by electric or hydrogen power. Based on estimation by CICC sector research teams, around 22% of fossil-fuel energy (equivalent to 1.34bnt of standard coal) cannot be replaced, which accounts for around 3.4bnt in carbon dioxide emissions.

Cement: According to the estimation from Gao Changming and other academics, they expect that the theoretical substitution ratio (TSR) in China's cement industry to reach 25% in 2030 and 70% in 2050. Carbon dioxide emissions from calcium carbonate consumption and fuel consumption are 0.36 tonnes and 0.18 tonnes per tonne of cement. Even considering the reduction in the total output of cement through recycling and overall infrastructure development, the remaining carbon dioxide will still need to be offset by carbon capture.

Steel: If directly reducing iron ore in a blast furnace, it is possible to use 100% non-fossil fuels but not feasible for production processes. So the CICC commodity team's estimate is made on the assumption that steel production requires fossil fuels and that coke remains a vital reducing agent.

Aluminum: Aluminum oxide production needs carbon capture technology as it cannot avoid the use of fossil fuels.

6.4.4 Costs and Green Premiums of Non-power Carbon Neutrality Solutions

As mentioned earlier, we estimate that electric power will not meet the remaining 30% energy consumption demand in our carbon neutrality case. To achieve zero-emissions in non-power energy consumption, we estimate 33% of energy can be replaced by hydrogen power, and the rest, i.e. coal, petroleum, and natural gas will need to adopt carbon capture technology. Based on these assumptions, we compare the carbon neutrality and base cases, and estimate the green premium of the non-power energy supply at 175% in 2021. If the costs of fossil-fuel energy remain unchanged and that of carbon capture and hydrogen power decline, we expect the sector green premiums of non-power sector to fall to 57% in 2030 and 14% in 2060, still above zero. In sum, to achieve carbon neutrality, the overall cost of non-power energy consumption will likely rise.

For hydrogen power, we estimate the per unit hydrogen-based power costs will fall from around Rmb13,000/tonne of standard coal in 2021 to around Rmb4,000/tonne of standard coal in 2060, still higher than the estimated weighted average power costs of around Rmb2,400/tonne of standard coal in 2021. Thus, hydrogen power will still have a green premium by 2060.

For carbon capture, we expect that per tonne carbon dioxide capture costs to fall from Rmb465/tonne (our estimate) in 2021 to Rmb262/tonne in 2060. As carbon capture is applied in the end-process, it creates extra costs compared with the base scenario and its green premium will stay above zero.

Based on our estimates, we note the cost of hydrogen power is lower than the diesel oil plus carbon capture solution (Fig. 6.10). As it is difficult for coal power or natural gas to adopt carbon capture technology, it would be easier to use hydrogen power in diesel-based consumption scenarios. Given practices in foreign countries and subsidy policy for renewable energy in China, we suggest that supporting policies kick in when the green premium of non-electricity energy technologies, i.e., hydrogen power and carbon capture, is near 200%.

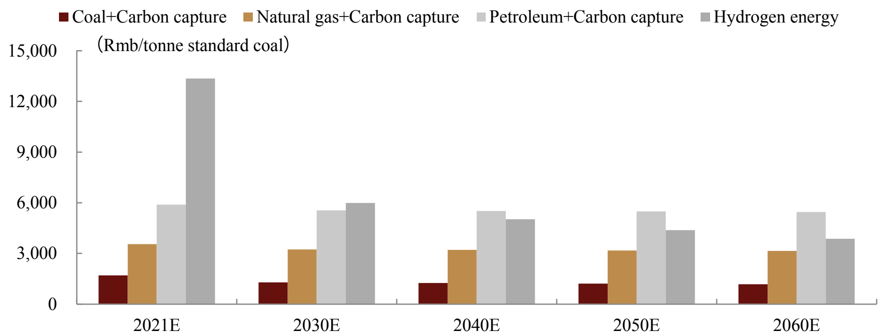


Fig. 6.10 Comparison of non-power zero-carbon solutions. *Source* CICC Research

6.5 Policy Recommendation: Power System Reform Accelerates Non-fossil Energy Absorption and Helps the Development of Hydrogen Power

6.5.1 *Policy Recommendation for the Power Sector: Stabilize New Energy Absorption*

First, continue to improve the ancillary power system service market. Improving ancillary power system services is a good choice for China, as power storage is still not economically feasible. The government can enhance pricing mechanisms, incentivizing flexible power sources (thermal power with adjustable output, pumped-storage hydropower, power storage and demand response) to participate in power dispatching. Thus, when renewable resources account for the majority of output, it can lower the proportion of flexible resources to reduce the waste of renewable electric power.

Second, begin to adopt emission trading system. We think the government should build support mechanisms for emission trading system. Electricity's spot prices reflect real-time demand and supply conditions. This facilitates peak shaving and valley filling. Moreover, it enables peak-valley spread arbitrage, accelerating the growth of energy storage demand. However, a mature trading system take time and effort to build. The spot market may face uncontrollable risks, such as fluctuations in prices. When electricity spot market can guide flexible resource investment, as well as operation and demand response, we expect the government to build effective supporting mechanisms to avoid potential risk in extreme scenarios.

Third, promote pilot energy storage projects. Energy storage helps enhance the stability and flexibility of new energy power output. We believe this is an effective way to raise renewable energy absorption capability in the parity era of "new energy plus energy storage solutions". We believe energy storage reform at new-energy power plants is the most effective and least challenging way to promote energy storage. It doesn't need a new market mechanism and will not challenge the power grid's safety requirements. However, such a reform may lower ROI. Apart from policy support, we think the government can launch pilot energy storage projects, offering subsidies, tax reductions, and preferential policies to facilitate project developers' land use and grid connections.

6.5.2 *Policy Recommendation for Non-power Sector: Building Supporting System for Carbon Reduction; Establishing Reward and Penalty System to Fuel Clean Energy Development*

First, the government may build supporting systems for carbon reduction. Taking coal-to-gas and coal-to-electricity programs as an example, they may encounter problems including unstable natural gas supply, subsidy delays, and insufficient infrastructure construction such as transmission pipelines. Apart from technology availability, we think the supporting system is crucial in planning low-carbon and zero-emission technology promotion.

Second, the government should launch a carbon trading rewards and punishment system to make the industrialization of new technology more economical. We expect carbon trading to accelerate upgrades of low-carbon technology in the non-power sector by limiting total emissions. Companies with large emissions will suffer environmental costs that weigh on production and operation and weaken their competitiveness. We expect carbon trading to push companies to reduce carbon emissions so as to lower costs. We believe subsidies for zero-emission or carbon-negative technologies (e.g., hydrogen power and carbon capture) will likely motivate companies to make the required changes to their operations.

Chapter 7
Green Manufacturing: Carbon Emissions Reduction Roadmap of Carbon Intensive Sectors

Abstract The implementation of green manufacturing is a key step for China to achieve carbon neutrality. According to China Emission Accounts and Datasets (CEADs), energy-intensive industries such as steel, cement, oil and gas, chemicals and non-ferrous metals, were responsible for about 36% of China's total carbon emissions in 2017. This chapter analyzes changes in the green premiums of the steel, cement, non-ferrous metals, general manufacturing industries, as well as oil, gas and chemicals at different stages of development to explore how manufacturing sectors may become carbon neutral. Having analyzed total carbon emissions and green premiums of various sectors, we conclude that the higher the proportion of carbon emissions from internal production processes is, the higher green premiums are and the more difficult it is to reduce carbon emissions. As thermal power may be gradually replaced by renewable energy sources, we believe emissions from power consumption may decline sharply. If emissions of an industry mainly come from internal production processes rather than electricity consumption, such an industry would need to upgrade technological routes or adopt carbon capture technologies to reduce emissions, which means a higher green premium. We believe 2021–2030 may be the toughest period for emission cuts in manufacturing industries. While it is relatively easier to cut emissions from power generation, electricity consumption is not the main culprit for carbon emissions in most energy-intensive industries. Therefore, these industries may face both financial and technological problems in cutting emissions, especially in the early stages before 2030. Based on the direct emissions from internal production processes (without taking into account emissions from power consumption), we estimate a green premium ratio (i.e., magnitude of cost increase to achieve net-zero emissions) of 21% for steel, 151% for cement, 4% for aluminum, 61% for chemicals, and 8% for oil and gas sectors in 2019. Earnings of general manufacturing industries may decline about 3% if the green premium is taken into account. We believe these industries will need supportive public policies in this period to help them solve their problems, complete technology upgrading, and find a feasible path for emission cuts. During the period from carbon peak to carbon neutrality, we believe energy-intensive industries may face much milder pressure on emission reduction as these industries can finally develop a feasible and affordable roadmap for emission cuts. With low-carbon transition and falling aggregate supply and demand of some energy-intensive industries, we believe the green premium ratio

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_7

(based on emissions from internal production processes) may decline to 6.7% for steel, 67.5% for cement, 2.0% for aluminum, −0.8% for chemicals, and −3.3% for oil and gas sectors in 2060, much lower than the current levels.

7.1 Cost of Zero Emissions: Analyzing the Carbon Neutrality Roadmaps of Manufacturing Industries from Perspective of Green Premiums

This chapter analyzes changes in the green premiums of the steel, cement, non-ferrous metals, oil and gas, chemicals, and general manufacturing industries at different developing stages to explore how manufacturing sectors might become carbon neutral.

First of all, under the current technological conditions, the additional cost of achieving zero emissions in major manufacturing industries is very high. Therefore, it is difficult to achieve carbon neutrality in manufacturing sectors overnight. Reducing carbon emissions must be conducted progressively at a cost that the industry itself and downstream sectors can afford. The current carbon emissions of energy-intensive manufacturing industries can mainly be classified into two categories: electricity and non-electric emissions. The electricity category can achieve zero emissions by converting thermal power into low-carbon electricity such as wind power and photovoltaic power generation, resulting in lower additional costs. However, it is difficult for the non-electric category to achieve zero emissions without the help of carbon capture technology, and achieving zero emissions is costly. Overall, apart from the general manufacturing industry, the current green premium level of key manufacturing industries is generally high. We estimate that in order to achieve zero emissions with direct and indirect emissions reduction method, the green premium ratios of the steel, cement, electrolytic aluminum, basic chemical, and petrochemical industries are 22%, 156%, 34%, 66%, and 8%, respectively. The profit of the general manufacturing industry will drop by about 3% from the level of 2019. If considering the non-electric emissions only, the green premiums of steel, cement, electrolytic aluminum, basic chemicals, and petrochemicals in 2019 were 21%, 151%, 4%, 61%, and 8%, respectively. Most industries will not be able to afford the internalized carbon neutralization costs without passing on rising costs to downstream. The cement industry, which has the highest green premium, would even need to pay about 3 years of net profit to achieve zero emissions at this point. Therefore, it is difficult to achieve carbon neutrality in manufacturing industry now. It needs to be done step by step, and public policy tools should be used to guide enterprises to and promote technological innovation. Various industries need to develop practical emission reduction paths based on actual conditions of their industries and downstream sectors (see Fig. 7.1).

Second, we discuss whether various industries can use existing technological innovations and available public policy tools to explore an optimal emission reduction path. The manufacturing industry still needs to use policy tools such as supply restriction in the early stages of carbon peak, while after carbon peak is reached,

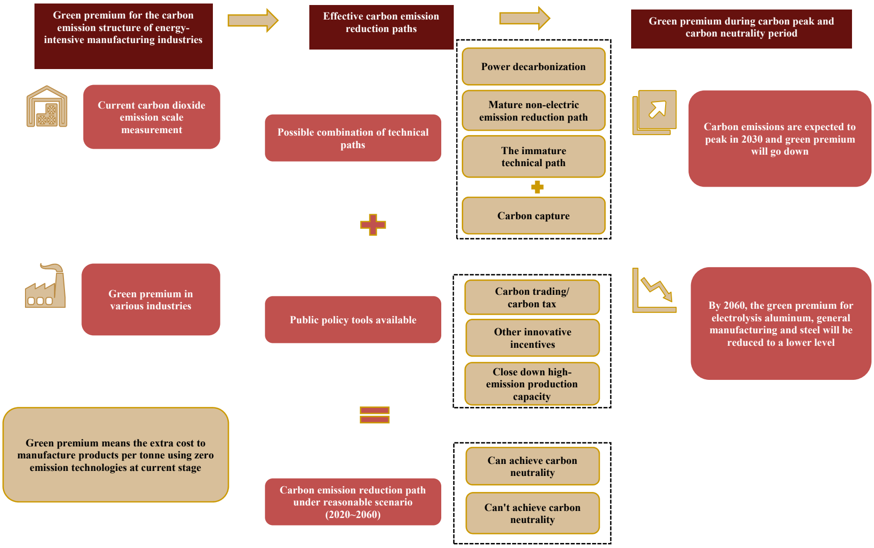


Fig. 7.1 A mind map for green manufacturing. *Source* CICC Research

the mature carbon reduction technology and the natural decline of industry production and sales will become important drivers of emission reduction. First, since the main sources of carbon emissions of aluminum and general manufacturing industries come from electricity, it is the least difficult to reduce emissions. Carbon peak and reduction of carbon emissions can be achieved through imposing proper production limits as well as restricting the upper limit of production capacity at the initial stage. As the proportion of thermal power gradually reduces to zero, we expect electricity-related carbon emissions to be close to zero by 2060. Second, the steel industry can convert high-emission blast furnace production capacity into low-emission electric arc furnaces (this technology is mature but faces constraints from the availability of raw materials. We expect the proportion of steel production using electric arc furnaces to reach 60% by 2060). The adoption of low-carbon transformation by blast furnaces could be another solution, but it is not yet at a mature stage. In the early stages of carbon peak, certain restrictions on production capacity and output still need to be imposed. In the middle and later stages, public policy tools, such as carbon tax, carbon trading mechanism, and pilot subsidy mechanism can be used to encourage enterprises to reduce emissions and achieve industrial upgrading. Third, under the current conditions, as cement and chemical industries lack mature technologies to significantly reduce carbon emissions, they are highly dependent on carbon capture technologies. The early carbon peak mainly relies on restrictions on production capacity and output. It is also necessary to adopt policies to encourage enterprises to carry out technological transformation to reduce emissions.

In order to quantify the effectiveness of emission reductions, we also forecast the carbon emissions of various industries from 2020 to 2060 under reasonable deductions on future circumstances. This shows that most industries are expected to reach peak carbon emissions ahead of schedule and achieve carbon neutrality with the aid of carbon capture in 2060. Other than prompting technologies upgrading and limiting production, forcing retirement of outdated production methods could also be an important tool. The impact on these industries is similar to supply-side reforms. Based on our estimates, most industries are likely to achieve carbon peak around 2030 given the policies above. From 2030 to 2060, the growth of production and sales in some industries might slowdown or even decline. After the new technology reaches a mature stage, the technological transformation of enterprises will be promoted on a larger scale, which will lead to reduction in carbon emissions per tonne of products. By 2060, the steel, cement, aluminum, and the chemical industries are expected to reduce carbon emissions by 79%, 78%, 90%, and 63% compared to 2019 levels, respectively, without the use of carbon capture technology. As the cost of carbon capture drops sharply, the technology will be used to achieve carbon neutrality, and become affordable for these industries. As a result, these industries are expected to become carbon neutral. We expect the general manufacturing industry to fully achieve carbon neutrality without the use of carbon capture technology by 2060.

Finally, we calculate the green premiums of various industries during the carbon peak (2030) and carbon neutrality (2060) periods under reasonable circumstances to observe whether the burden of achieving carbon neutrality on enterprises will decrease significantly over time and lead to a positive conclusion. For industries in which carbon emissions are mainly derived from electricity, namely aluminum and general manufacturing, and industries that have mature paths to significantly reduce carbon emissions, namely steel, their green premiums should decline sharply and will reach an affordable level, or even close to zero. For industries that have not yet established a mature emission reduction path, such as cement and chemical, the green premium will also fall sharply. Companies can carry cost pressures through appropriate price increases.

In summary, manufacturing industries will likely face the greatest challenge in reducing emissions in the following 10 years, and the pressure may be reduced significantly after that. In these 10 years, the industries face both technical difficulties and cost dilemmas. To achieve carbon neutrality under current conditions, all high-energy-consuming manufacturing industries except for general manufacturing will face substantial increases in costs and potentially heavy losses. Therefore, in the early stages of reducing carbon emissions, it is necessary to take step-by-step approach, and the government should provide strong support to enterprises using public policy such as carbon trading mechanisms, pilot subsidies, and production restrictions to help overcome difficulties. After 2030, the green premiums of various industries are likely to decline sharply. In 2060, the green premium ratios of steel, cement, aluminum, chemicals, and petrochemicals will be 6.7%, 67.5%, 2.0%, −0.8%, and −3.3%, respectively, all of which will drop significantly compared to

2019. Therefore, with technological innovation and policy support, manufacturing industries will eventually find a reasonable and affordable way to reduce emissions.

7.2 Steel Industry: Mature Emission Reduction Path with Electric Arc Furnace Gradually Demonstrating Advantages

7.2.1 Industry Green Premium: Cost for the Steel Industry to Achieve Carbon Neutrality at the Current Stage

The steel industry is the industry with the largest carbon emissions in China industrial sectors and a pillar industry for economic and social development. Therefore, carbon neutrality in the steel industry is crucial to China carbon neutrality. We estimate carbon emissions from China's steel industry might reach 1.54bn tonnes in 2019, accounting for 47% of carbon emissions from industrial sectors and 18% of China's total carbon emissions. The steel industry is the largest carbon emitter among all industrial sectors.

High carbon emissions have led to a relatively high level of green premium in the steel industry. We estimate that production of one tonne of steel using the blast furnace process emits 1.68tonnes of carbon dioxide, of which 1.42tonnes comes from internal production processes and 0.26tonnes from electricity consumption. About 0.4tonnes of carbon dioxide is emitted for every tonne of steel produced using the electric furnace process. The main raw materials are iron ore and coke for blast furnace process and are steel scraps for electric furnace process. Having considered electricity consumption, we estimate the green premium for each tonne of crude steel produced is Rmb695, corresponding to a 22% increase of pre-carbon neutrality costs. It also implies an industry-wide green premium of Rmb690bn. Given that the average annual total profit of the steel industry was Rmb223bn in the past 10 years, the green premium of the steel industry in 2019 was approximately equivalent to 3 years of total profit for the steel industry.

The steel industry cannot fully internalize the costs of achieving carbon neutrality. We estimate that if the steel industry were to reach carbon neutral, and that all of the related costs were internalized in 2019, the cost to the steel industry would be Rmb690bn with a corresponding increase of Rmb695/tonne for crude steel. Together with oversupply and product homogeneity issues, we believe the steel industry will not be able to fully internalize the entire cost to achieve carbon neutrality. Without government guidance and support, it is difficult for the steel industry to achieve carbon neutrality on its own.

7.2.2 Technology Roadmaps for Carbon Emissions Reduction in the Steel Industry

Replacing traditional blast furnace with electric arc furnace is the most effective and economical technology roadmap. Electric arc furnace can significantly reduce carbon emissions with lower per unit costs and shorter production cycles. Moreover, China's current dependence on imported iron ore is as high as 90%, making the switch from blast furnaces to electric arc furnaces an essential measure to help China gradually reduce its dependence on imported coking coal and iron ore. It would also help China secure the supply of raw materials in important industrial sectors. With the target of carbon neutrality, we expect China's demand for coking coal and iron ore to decline by 60% by 2030 and by 70% by 2060 thanks to the rising supply of steel scraps, close to the current level in the US and Europe. We expect China's demand for coking coal and iron ore to drop by 60% and 70% as of 2030 and 2060, which will help China achieve independence in raw materials.

China is currently exploring new technologies to develop a more environmental friendly metallurgy industry. One path is hydrogen metallurgy and the other is non-hydrogen direct reduced iron. Hydrogen metallurgy can greatly reduce carbon emissions of blast furnaces, but it remains too early for large-scale applications. Non-hydrogen direct reduced iron technology is a mature technology which can significantly reduce carbon emissions from blast furnaces. However, its applications in China are constrained by gas sources and equipment. We believe China's steel industry needs to continuously explore new technologies to reduce carbon emissions. We see three main potential approaches (1) green energy; (2) separation and recycling of carbon dioxide from blast furnaces; and (3) recycling of carbon monoxide in blast furnace gas.

We suggest that the steel industry adopt emissions trading mechanisms to help reduce carbon emissions with the current emissions reduction strategies. Reduction of carbon emissions in the steel industry requires decades of continuous effort, and all measures targeting the goal should be implemented progressively. In the early stages, it is necessary to impose certain restrictions on production capacity and output to reach carbon peak. In the later stages, we suggest using public policy tools to encourage enterprises to reduce emissions independently. On the one hand, leading steelmakers may be more willing to switch to electric arc furnaces as the cost of electricity can be reduced to strengthen their cost advantages. On the other hand, the emissions trading mechanisms can generate additional revenue.

7.2.3 Lowering the Green Premium: Will the Steel Industry Achieve Carbon Peak and Carbon Neutrality as Planned?

Due to the continuous development of electric arc furnace technology and the policy constraints, the steel industry is expected to achieve carbon peak before 2030.

However, due to limited scrap steel resources, electric arc furnaces cannot completely replace blast furnaces. Carbon neutrality can only be achieved with the support of carbon capture. We believe carbon emission reduction will be driven by two factors: (1) a sharp decline in demand for construction steel after China's urbanization rate gradually approaches 75%, which will drive the production of steel down to 0.88bn tonnes in 2030 and 0.65bn tonnes in 2060 (Fig. 7.2); and (2) the proportion of electric arc furnaces rising to 30% and 60% in 2030 and 2060. We estimate carbon dioxide emissions may reach 960mn tonnes in 2030, reaching carbon peak ahead of schedule, and we expect carbon dioxide emissions to fall further to 320mn tonnes in 2060, about 79% below the 2019 level. The steel industry is expected to achieve carbon neutrality when the cost of carbon capture technology becomes affordable.

By 2060, the steel industry is expected to fully internalize the cost of carbon neutrality, and to achieve zero carbon emissions. Taking electricity consumption into account, we estimate green premium for the steel industry (mainly the cost of carbon capture) are Rmb695, Rmb270, and Rmb115 per tonne of steel in 2019, 2030, and 2060, respectively (Fig. 7.3). With carbon emissions falling to 320mn tonnes industry-wide, the overall green premium for the steel industry may drop to Rmb74.4bn. As the proportion of green premium in the cost of steel manufacturing continues to drop, we expect that the cost of carbon neutralization can be internalized and the industry can achieve zero carbon emissions by 2060.

7.3 Cement Industry: Achieving Carbon Neutrality is Difficult. Demand and Cost of Carbon Capture are the Key

7.3.1 Industry Green Premium: Cost of Achieving Carbon Neutrality at Current Stage for Cement Industry

The cement industry is among the industries with the highest level of carbon emissions. We estimate that China's cement industry emitted 1.37bn tonnes of carbon dioxide emissions in 2019, accounting for 14% of China's total carbon emissions. Production of one tonne of cement emits 0.6tonnes of carbon dioxide, with 0.36tonnes from limestone production, 0.18tonnes from coal combustion and 0.05tonnes from electricity consumption.

The cement industry currently has no mature emission reduction method other than carbon capture. However, it is costly to achieve zero emissions through carbon capture. Currently, 99% of the production lines in the cement industry are dry-process clinker production lines and the technology system is mature. In the cement manufacturing process, carbon dioxide generated by electricity can be eliminated by outsourcing non-thermal power, and carbon dioxide generated from non-electric processes needs to be absorbed by carbon capture. We estimate that the carbon capture cost was about Rmb500 per tonne of cement in 2019. Assuming the cement

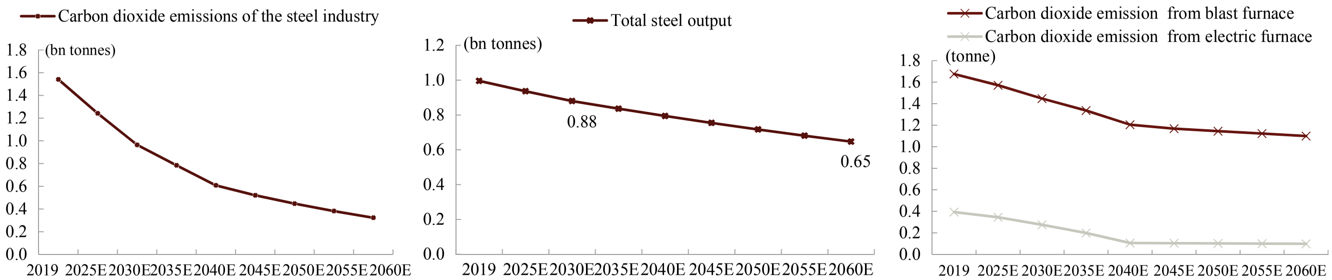


Fig. 7.2 Carbon emissions in the steel industry, China's steel production, and carbon emissions by blast and electric furnaces. *Source* Mysteel, China Iron and Steel Association, mid-term evaluation and long-term outlook of coal consumption in the steel industry during the 13th Five-Year Plan period, 2019 Energy Data, CICC Research

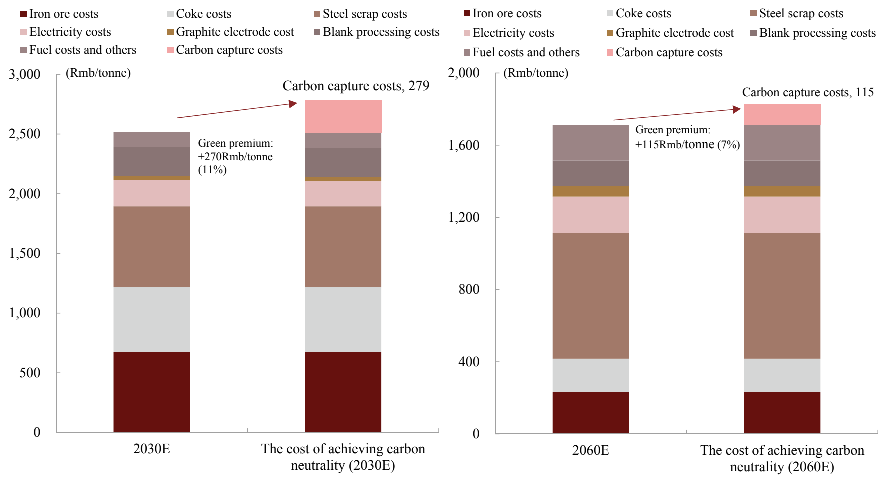


Fig. 7.3 Green premiums for leading steelmakers to achieve carbon neutrality through carbon capture in 2030 and 2060. *Source* Global status of CCS 2019, European Zero Emission, Technology and Innovation Platform, the National Petroleum Council, GCCS, Wind Info, CICC Research

industry was operating at net zero emissions in 2019, we estimate the green premium at Rmb278/tonne, implying an industry-wide green premium of Rmb647.8bn, three times the profit in 2019.

The cement industry cannot afford to internalize the full cost of achieving carbon neutrality. We estimate that if the cement industry were carbon neutral, and all related costs were internalized in 2019, the increase in total cost to the industry would have been Rmb650bn. The profit of the cement industry in 2019 reached a historical high of about Rmb186.7bn, implying net profit of about Rmb80 per tonne of cement. The total profit in 2015 to 2016 was only Rmb30 to 50bn, implying net profit of Rmb15-25 per tonne. Therefore, the cement industry will not be able to withstand this cost pressure even during high earning periods unless it can pass costs on to downstream participants. If cement manufacturers manage to increase their prices, the real estate, infrastructure, and rural construction sectors would likely see much higher costs.

7.3.2 Technology Roadmaps for Carbon Emissions Reduction in the Cement Industry

The cement industry has very limited ways to reduce carbon emissions per unit. Based on our discussions with industry associations and cement companies, it is difficult for the cement industry to significantly reduce per unit carbon emissions. There are only a few ways to reduce carbon emissions at a marginal level, mainly including:

First, reducing coal and electricity consumption through technological upgrading and renewable energy. The cement industry can reduce cement power consumption by one-third and coal consumption by more than 10% through waste heat power generation and use of alternative fuels.

Second, pushing forward decarbonization of the power sector. The cement industry mainly uses thermal power currently. However, as thermal power is gradually replaced by non-carbon energy sources or coal-fired power plants using carbon capture technology, we expect the electricity used in the cement industry to gradually become decarbonized.

Third, using low-carbon raw materials. The use of low-carbon alternative raw materials such as desulfurized gypsum and electric arc furnace slag can slightly reduce the carbon emissions caused by the decomposition of limestone.

The cement industry mainly relies on carbon capture and storage to achieve carbon neutrality. We expect these three technological pathways to help the industry gradually reduce the unit energy consumption. If technological upgrading can be achieved to reach a theoretically maximum level, the consumption of electricity, coal and raw materials could decline by 22%, 15% and 30%, respectively, for each tonne of cement by 2060. That said, carbon emissions per tonne of cement may remain as high as 0.4 tonnes in 2060. Therefore, the two main ways to achieve carbon neutrality in the cement industry in the future will still be technological transformation to reduce per unit carbon emissions and carbon capture. The current cost of carbon capture is high and it is likely to be relatively expensive in the future even with technological upgrading.

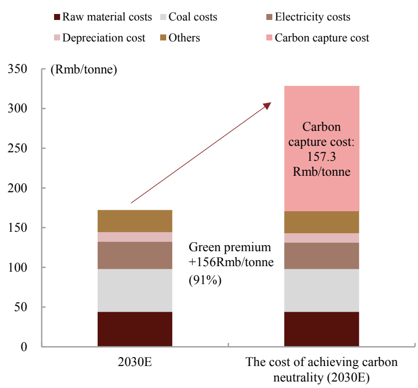
In terms of policy guidance, carbon allowance can be restricted in the short term and carbon tax or carbon trading can be adopted in the long term. Due to the technical difficulty in reducing emissions and high cost of carbon capture in the cement industry, it is difficult to afford the carbon at present. Thus, the cement industry mainly relies on the capacity and output restrictions of cement companies. In the long run, the industry also needs to encourage enterprises to pursue emission reduction through technological transformation by adopting policies such as carbon trading and carbon tax. Both carbon tax and carbon trading are suitable policies for guiding the cement industry to actively reduce emissions. However, compared with carbon tax, carbon trading adopts a flexible market-based mechanism that takes the large differences between profitability in different regions and time periods into account. It also enables companies that make bigger cuts in emissions to obtain some revenue as a reward.

In addition, China may unveil a pilot program that subsidizes and encourages cement manufacturers to use solid waste and waste heat to generate power and use other raw materials to replace limestone. Driven by the carbon trading mechanism and green subsidy policies, companies that actively explore emission reduction plans and focus on energy conservation and emission reduction may receive additional revenue from the sale of carbon indicators, pilot subsidies, and ultimately increase their market share. Meanwhile, companies that find reducing emissions difficult will gradually withdraw from the market and the industry will be further optimized.

7.3.3 Lowering the Green Premium: Feasible Paths to Carbon Peak and Carbon Neutrality in the Cement Industry

The cement industry has not yet found a mature way to achieve carbon neutrality without carbon capture. However, the green premium will gradually decline due to the progress in carbon capture technology. We estimate green premiums, which are mainly the cost of carbon capture in the cement industry, will be Rmb156 and Rmb106 per tonne of cement in 2030 and 2060, respectively, driving up manufacturing cost by 91% and 64% (see Fig. 7.4). As the technology advances, the green premium will decline amid the falling carbon capture expenses.

The decline in cement demand is key to the emissions reduction for the cement industry. We expect the cement industry to achieve carbon peak before 2030, and carbon neutrality by 2060 with the support of affordable carbon capture. We also expect that cement demand will decline significantly as the urbanization rate gradually increases. It is estimated that in 2030, domestic cement production will be between 1.9 and 2.0bn tonnes (see Fig. 7.5). By 2060, with reference to global per capita cement consumption, domestic cement demand will be between 760 and 770mn tonnes. In 2030, the entire industry's carbon emissions will be reduced to 1.07bn tonnes, which is lower than the current level of carbon emissions, and the cement industry is expected to achieve carbon peak ahead of schedule. In 2060, carbon emissions will be further reduced to 310mn tonnes, a 77% decrease from 2019. But without carbon capture, the industry still cannot achieve carbon neutrality. We estimate that due to the decline in total cement production in 2060, if carbon neutrality in the cement industry is achieved through carbon capture, the overall green premium of the industry will be Rmb80.6bn.



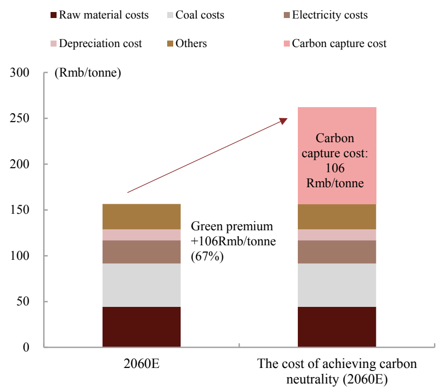


Fig. 7.4 Forecasted green premiums in the cement industry in 2030 and 2060. *Source* CSR report of ACC, cenews.com.cn, CICC Research

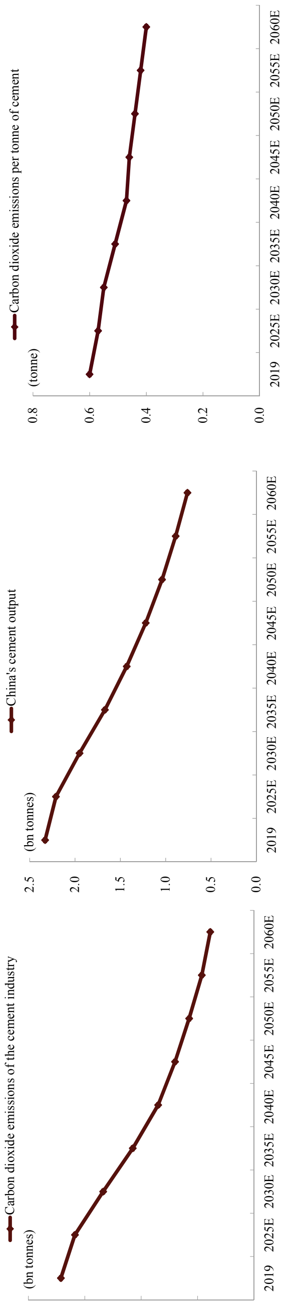


Fig. 7.5 Carbon emissions of the cement industry, China's cement output, and carbon emissions per tonne of cement. *Source* Qianzhan Intelligence, dcement.com, The Norm of Energy Consumption Per Unit Products of Cement, CICC Research

7.4 Aluminum Industry: The Decarbonization of Electricity is the Key to Carbon Neutrality

7.4.1 Industry Green Premium: Cost for the Aluminum Industry to Achieve Carbon Neutrality at the Current Stage

Aluminum is the main source of carbon emissions in the non-ferrous industry. According to our calculations, carbon emissions from China's non-ferrous metals sector reached 421mn tonnes in 2019, with aluminum production accounting for 363mn tonnes, copper about 11mn tonnes, lead 16mn tonnes, and zinc 31mn tonnes. Since aluminum production makes up 86% of emissions, making it the largest source of carbon emissions in the non-ferrous metals industry, we will mainly discuss the carbon reduction strategy for the aluminum industry. Based on our estimates, electricity consumption in the process of producing aluminum generates 279mn tonnes of carbon emissions. In the aluminum industry, electricity consumption contributes 80% of carbon emissions, and the remaining 20% are from internal production processes.

Since decarbonized power generation is still costly at this point, the green premium for the aluminum industry is high and cannot be internalized. Zero emissions can be achieved by replacing thermal power with clean energy and using carbon capture to deal with the remaining non-electric carbon emissions. However, the cost of using clean energy and carbon capture technology at the current stage is relatively high. The cost of electricity per tonne of electrolytic aluminum may increase by 50–60% compared to current levels with a switch to clean energy. We estimate that the green premium is at Rmb3,436 per tonne of aluminum to reach zero emissions in 2019, which may raise costs by 26.9%. The total green premium is Rmb122bn, which is equivalent to 2–3 years' worth of high-level net profit for the industry, or average net profit for 6–7 years.

7.4.2 Technology Roadmap for Carbon Emissions Reduction in the Aluminum Industry

The decarbonization of electricity is the key to reducing emissions in the aluminum industry. Decarbonization of electricity can reduce the industry's carbon emissions by 80%, and the remaining non-electricity carbon emissions need to wait for the cost of carbon capture to be lower. The production process of aluminum is "bauxite → alumina → electrolytic aluminum". The "bauxite → alumina" process mainly results in non-electric carbon emissions, accounting for 20% of the carbon emissions. Given that 90% of the current production has adopted a low-carbon process (Bayer method[1]), process optimization can only marginally reduce the per unit carbon emission. Therefore, it requires carbon capture to achieve zero emissions. We estimate that the cost of carbon capture per tonne of alumina in 2019 would be Rmb501, but will drop to Rmb262 by 2060. The "alumina → electrolytic aluminum" process creates carbon emissions by using electricity, accounting for 80% of the emissions. Zero emissions can be achieved by replacing thermal power with green electricity. We expect green electricity to have lower cost than thermal power electricity in the long run, and this process to achieve carbon neutrality by 2060.

In the early stages of carbon emission reduction, it is difficult for companies to afford the cost due to the high green premium. In order to meet the carbon peak target, policies need to impose certain restrictions on the supply side. The current policy has implemented a limit on the total carbon emissions of the industry, of which the impact may be similar to the supply-side reforms in 2016–2017. It helps balance supply and demand in the industry, reduce cyclical fluctuations of the industry's profits, and also promotes the development of leading companies.

In the long run, it will become possible to achieve carbon neutrality through technological advancements as the cost of green energy and carbon capture decreases. It is important to use policies to encourage enterprises to reduce electricity consumption, upgrade to green energy, and adopt carbon capture technology. More importantly, the government may use carbon trading or carbon tax mechanisms to strengthen the cost advantages of companies that use less thermal power. Companies with hydro-power or other clean power generation facilities will have notable cost advantages, whereas small companies that do not perform well in emission reduction may be forced out of the market. Considering the sharp profit fluctuations in the aluminum industry (electrolytic aluminum industry has brought profit of less than Rmb200 per tonne in the past 5 years, but could also exceed Rmb2,000 at the highest level) and regional variations, we believe that carbon trading may be more suitable for companies to adjust their production compared to carbon tax, which involves a unified carbon price. In addition to carbon trading, we also recommend using subsidies to encourage enterprises with suitable conditions to develop secondary aluminum, establish their own green power plants, or increase the use of green energy.

[1] The main processes for preparing alumina from bauxite are Bayer method, sintering method and hybrid method. Compared with the latter two methods, the Bayer method can reduce carbon emission per tonne of alumina by about 67% and 49%.

7.4.3 *Lowering the Green Premium: A Feasible Path for Carbon Peak and Carbon Neutrality in the Aluminum Industry*

Based on previous technology roadmaps and public policies, we expect the aluminum industry to achieve carbon neutrality before 2030. Aluminum Corporation of China and Shandong Weiqiao Pioneering Group jointly issued the *Joint Proposal for Accelerating the Green and Low-Carbon Development of the Aluminum Industry* in early 2021, striving to reach their peak production capacity and output for domestic alumina and electrolytic aluminum during the 14th Five-Year Plan period. It also estimates that the capacity ceiling of the aluminum industry is around 45mn tonnes. Given that the growth in supply and demand is expected to slow significantly, we expect the aluminum industry to achieve carbon peak before 2030 with the help of new energy. By 2030, we estimate that the total carbon emissions of the aluminum industry will be about 258mn tonnes, a decrease of 28.9% from 2019.

We expect the aluminum industry to achieve carbon neutrality by 2060 with the support of affordable carbon capture technology. Using green electricity in the production process, carbon emissions per tonne of aluminum might be reduced by 80% compared to the current level. At the same time, the development of carbon capture technology is expected to bring down green premium per tonne of aluminum from Rmb554 to Rmb262. We estimate that the carbon emissions of the electrolytic aluminum industry in 2060 will be about 38mn tonnes with green premium of only Rmb4.89bn. The green premium can be internalized by the industry and therefore carbon neutrality might be achieved by then.

Green premium for aluminum industry is expected to decline significantly as the cost of green energy and carbon capture declines. Even considering the cost of switching to green energy, the green premium per tonne of the electrolytic aluminum in 2030 and 2060 will be Rmb1,079 and Rmb262, respectively (see Fig. 7.6), which mainly comes from the cost of carbon capture and green energy usage. The cost of electrolytic aluminum per tonne will increase by 8.3% and 2.0%, respectively. The decline in the green premium is also mainly due to the decline in the cost of carbon capture and green power energy. By 2060, with development of green electricity, overall carbon emissions will also decline, and the remaining non-electric carbon emissions will decline to a minimal level (see Fig. 7.7). If carbon neutrality is achieved through carbon capture, we estimate that the industry's green premium per tonne will be as low as Rmb262, which is more affordable for aluminum companies.

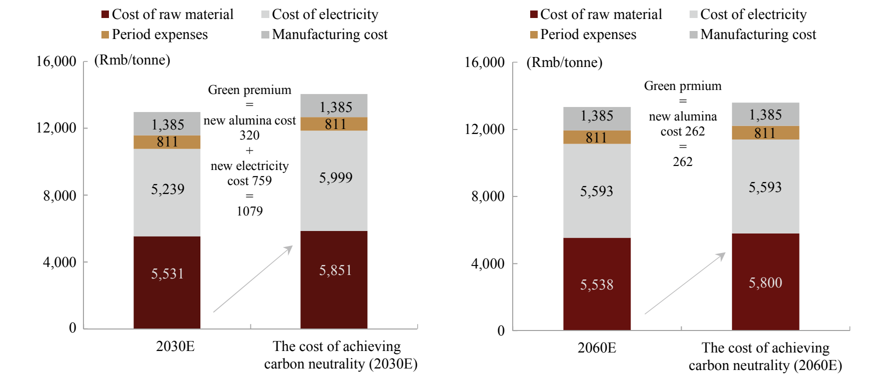


Fig. 7.6 Green premiums for aluminum industry to go carbon neutral through carbon capture in 2030 and 2060. *Source* Woodmac, Corporate filings, Analysis on the Guidelines for Accounting Methods and Reporting of Greenhouse Gas Emissions of Chinese Aluminum Manufacturers, CICC Research

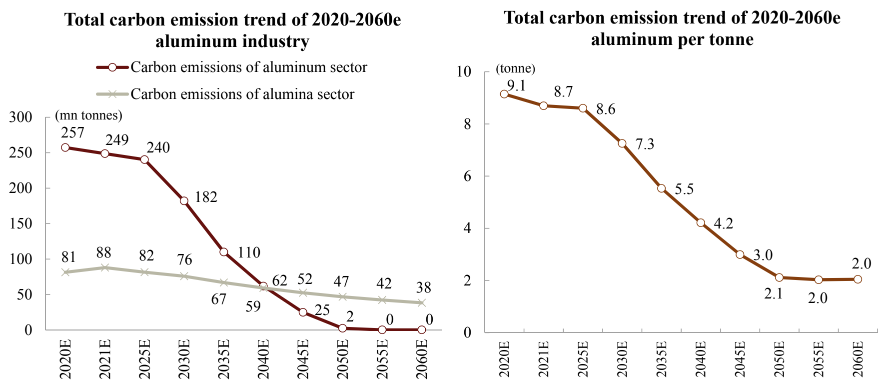


Fig. 7.7 Carbon emissions trend for alumina and aluminum industries in 2020–2060. *Source* Woodmac, CNKI, tanpaifang.com, CICC Research

7.5 Chemical Industry: When Carbon Negative Becomes Possible

7.5.1 Industry Carbon Emission: Cost for the Chemical Industry to Achieve Carbon Neutrality at the Current Stage

The chemical industry can be divided into two main fields: Petrochemicals and basic chemicals. In chemical industry, the replacement of naphtha and coal faces substantial pressure from heavy energy consumption in the chemical synthesis process. Looking at the consumption structure of chemical engineering, naphtha and coal consumption in chemical synthesis makes up the most of total consumption. Coal is not only one of the main synthetic raw materials, but is also one of the main energy sources. Carbon emissions of general chemical manufacturing mainly come from two processes: (1) energy consumption, including electricity required to operate equipment and steam for production environment; and (2) chemical reaction during the production of chemical products. To take the production of synthetic ammonia as an example of chemical reaction: in the first step of turning coal to gas, one unit of carbon and one unit of H_2O should theoretically generate one unit of CO and one unit of H_2. But in reality, the transformation cannot be 100% efficient. If natural gas, coal and oil are used directly as fuels or energy during the process of producing chemicals, that energy may be replaced by green energy. However, if this energy is used as raw materials in chemical reactions, it would be difficult to be replaced. The demand of chemicals will continue to grow along with economic and social development.

The production of synthetic ammonia and methanol accounts for a large proportion of emissions in the chemical industry. Based on China's standards, we estimate that the total carbon emissions of important products such as methanol, synthetic ammonia, ethylene and propylene account for 61% of total carbon emissions.

Despite sharp divergence among different segments, the overall green premium for the chemical industry is high. We believe that under current conditions, the path for carbon emissions of combining green energy with carbon capture and storage is the most suitable for the industry. Due to the differences in energy consumption and carbon emissions in various reactions, as well as the variations in the cost of carbon capture (Rmb100–420 per tonne) as a result of different CO_2 concentration levels, there is large variation in the green premiums for different sub-sectors in the chemical industry. The distance between carbon source and storage location as well as the resources available at the location will also lead to discrepancies in cost of transportation and storage.

At the same time, it is difficult to accurately measure the green premium of all sub-sectors in the chemical industry. Since methanol, synthetic ammonia, and ethylene account for a large proportion of the production capacity and carbon emissions, and they are also indispensable basic chemical products, we use them as examples to understand the amount of emissions in this industry. We have found that in the three sub-sectors, the path of combining current technology and carbon capture and storage technology is more economically preferable. Our analysis indicates that green premium ratios of chemicals and petrochemicals are 56.9% and 7.9%, respectively, in 2021. If carbon emissions from electricity consumption are not taken into account, these figures are 53.2% and 7.4%.

The chemical industry can absorb green premiums internally, but profitability may decline significantly with the current cost to achieve zero carbon. Given the sharp divergence among different segments in this analysis, we use a holistic method to estimate an industry-wide green premium. If the chemical industry reached carbon neutrality in 2019, total costs would have increased by Rmb250.74bn leading to a 36.7% industry-wide decline in profit (calculated by "cost of carbon capture multiplied by amount of emission" factoring in electric emissions). According to the National Bureau of Statistics, the total profit of the chemical industry in 2019 was about Rmb683.756bn, and the industry profit would have dropped by 36.7% after carbon neutrality. Even with the high level of profit in 2017, the industry profit after carbon neutrality would still have dropped by 24.4%. If new technologies were to be adopted, the cost of carbon neutrality could not be internalized since new technologies would be immature and expensive. Therefore, we believe the chemical industry could bear the cost of carbon neutrality by fully utilizing carbon capture and storage, but would have resulted in serious decline in profit. Besides, the downward transmission would have caused the cost of terminal infrastructure, consumption and other industries to rise sharply. In the meantime, we need to pay attention to the risk factors brought about by large-scale storage, and it is necessary to improve the feasibility of new technologies by reducing costs.

7.5.2 Technology Roadmaps for Carbon Emissions Reduction in the Chemical Industry

Multiple technologies are being used to help the chemical industry achieve net zero or negative carbon emissions. Given the large number of sub-sectors, the chemical industry needs different roadmaps to achieve carbon neutrality. (1) Carbon emissions attributable to electricity and energy consumption needs can be eliminated by outsourcing zero-carbon electricity; (2) Calcium carbide is widely used in current PVC production. As the ethylene method becomes mainstream, demand for calcium carbide products should drop sharply or even fall to zero, leading to carbon neutrality; (3) Carbon capture and storage technology plays an important role in helping the industry reduce emissions. Carbon emissions from coal chemical industries can only be handled through carbon capture given the current technology; (4) Biomass is a high-quality raw material that can help achieve carbon neutrality; (5) Products such as methanol and olefins can be produced through direct synthetic transformation of carbon dioxide and hydrogen. This process has net negative emissions, and the entire process has net zero emissions; and (6) Improving thermal efficiency or reaction efficiency can help achieve energy savings and emissions reduction. In this section, we will discuss the last four technology roadmaps.

Carbon capture and storage technology plays a key role in building a resilient energy system in China with its flexibility and sustainability, and it is especially important in China's coal-dominated energy system.

Use of biomass as raw material has strong potential. Biomass raw materials are mostly renewable and have varied sources. China's total biomass reserves are equivalent to 460mn tonnes of standard coal (this figure varies sharply based on different studies).

Chemical engineering synthesis with carbon dioxide and hydrogen can replace the current technology and achieve zero carbon emissions. This method uses hydrogen and carbon dioxide to synthesize methanol and gas. For instance, hydrogen from electrolysis of water and carbon dioxide can be directly used to synthesize olefins. This process consumes a large amount of carbon dioxide, resulting in negative emissions for the whole process.

Energy conservation and emissions reduction are also important in many sub-sectors. Through technological upgrading, the amount of raw materials for reaction will be reduced. Technological advancements can also help reduce energy consumption and carbon emissions. Popular methods are: (1) Improving reaction catalyst activity and easing requirements for reaction environment; (2) Introducing energy saving production equipment and other new equipment; and (3) Improving the efficiency of energy regeneration of waste heat.

7.5.3 Policy Guidance and System Building for Emissions Reduction are Crucial for the Chemical Industry

Given the numerous sub-sectors, different product markets and complex technological roadmaps, we believe policy guidance is appropriate for the chemical industry.

Carbon tax and carbon trading mechanisms can naturally guide companies to upgrade production methods and reduce energy consumption. With the help of some government restrictions, leading companies with low per unit carbon emissions and companies with advanced production methods will enjoy comparative advantages.

Policy guidance can also encourage innovation by subsidizing new technologies such as zero-carbon biomass and carbon dioxide conversion and utilization technologies. Additional investments in advanced technologies such as advanced electrolytic hydrogen technology and new material innovation projects such as lithium battery materials can reduce the R&D cost.

Introducing supportive policies to subsidize recycling of chemical products such as PET would also lower production of related products and eventually reduce carbon emissions.

7.5.4 Lowering the Green Premium: A Feasible Path for Carbon Peak and Carbon Neutrality in the Chemical Industry

There are various technological approaches to achieving carbon neutrality in the chemical industry. We calculate green premiums of the synthetic ammonia, methanol, and ethylene industries under two roadmaps: (1) Traditional approach plus carbon capture and storage; and (2) C1 chemical engineering with green hydrogen energy and carbon dioxide as raw materials (including AEC, PEM, SOEC). Both roadmaps can help the industry achieve carbon neutrality.

As shown in Table 7.1, the second approach lowers the green premium more

Table 7.1 Production cost of synthetic ammonia (via clean electricity vs. traditional approach) and green premiums

Scale: 2,000 tonnes NH3/day	2021				2030				2060			
	AEC	PEM	SOEC	Traditional approach	AEC	PEM	SOEC	Traditional approach	AEC	PEM	SOEC	Traditional approach
Green premium	3,292	3,450	3,780	979	762	773	1,557	582	308	194	−13	427
Actual green premium	979				582				−13			
Scale: 6bn tonnes MTO/year	2021				2030				2060			
Green premium	12,137	12,692	13,851	416	2,287	2,323	4,878	247	857	487	−188	181
Actual green premium	416				247				−188			

Note Assuming solar power price may drop to Rmb0.14/KWh in 2060, the hydrogen production cost from SOE electrolysis would be Rmb6.81/kg. Without taking into account emissions from power consumption, the green premiums would be Rmb979, Rmb583, and Rmb427 per tonne in 2021, 2030, and 2060, respectively
Source CICC Research

significantly. Although both approaches would result in negative green premium, the cost of the second approach would be higher than the first one by 2050, suggesting that new technology may replace the traditional approach by that time. We also reckon that carbon neutral technology without carbon capture is the better approach and deserves the corresponding cost, so the second approach could be implemented gradually before 2050.

Using previous calculations, we estimate the carbon emissions of the chemical industry. First, we estimate the output growth of the chemical industry. The growth rate will be around 1% before 2030 and plateau after 2030. Also, the progress in innovation of traditional technology will reduce the carbon emission coefficient by 0.5% every year. The use of "green hydrogen + carbon dioxide" technology will have an increasing penetration rate of 5% in 2030 and 70% in 2060. The penetration rate of substitutional raw materials such as biomass will have a penetration rate of 1% in 2051 and 10% in 2056. With carbon capture and storage technology, the chemical industry can reach carbon peak in 2030 and reach emissions of -14.2bn tonnes in 2060 (see Fig. 7.8).

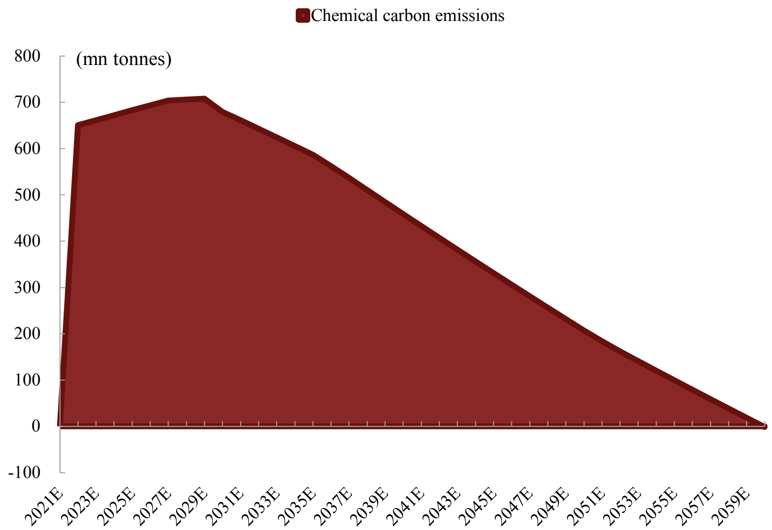


Fig. 7.8 Estimations of carbon emissions of the oil & gas and chemicals industries in the next 40 years (taking carbon emissions from electricity consumption into account). *Note* Assuming carbon consumption coefficient is 1.375 for methanol. Carbon consumption coefficient refers to amount of carbon dioxide that can be absorbed by one tonne of product. *Source* sci99.com, baiinfo.cn, CICC Research

7.6 General Manufacturing Industry: Achieving Carbon Peak; Using Clean Energy to Achieve Carbon Neutrality

7.6.1 Industry Green Premium: Cost for the General Manufacturing to Achieve Carbon Neutrality at the Current Stage

The general manufacturing industry accounts for only about 2% of overall carbon emissions in China. However, the general manufacturing industry involves a wide range of downstream industries, and some production processes and production equipment are highly versatile. Therefore, The R&D in the general manufacturing sector can play an important role in helping many sectors achieve carbon neutrality.

Carbon emissions from general manufacturing amount to 205mn tonnes per year, with emissions from electricity accounting for 2.2% of China's total carbon emissions and 5.7% of the manufacturing sector's emissions. Electricity consumption contributes 70% and internal production processes 30% of total carbon emissions from the sector. In terms of annual contribution, industries with heavier emissions are: Raw coal (128mn tonnes), coke (23mn tonnes), natural gas (22mn tonnes), diesel (8mn tonnes), gasoline (6mn tonnes), other washed coal (4mn tonnes), other gases (4mn tonnes) and coke oven gas (1mn tonne). The top five industries together account for more than 95% of carbon emissions. Of these, emissions from coal mainly correspond to electricity and emissions from coke mainly correspond to metallurgy. Therefore, reducing power consumption and reducing carbon emissions from metallurgical casting are key to reduce the overall carbon emissions of the general manufacturing industry.

The general manufacturing industry can achieve carbon neutrality through clean energy substitution. Power consumption by general manufacturing accounts for about 70% of carbon emissions, so it is easy and economical to achieve carbon neutrality by clean energy substitution. Producing green electricity is 11% more expensive than current hybrid electricity productions. The use of electricity and hydrogen energy are the two main paths for energy consumption and metallurgy. We assume that the cost of achieving carbon neutrality. Overall, the green premium in the general manufacturing industry is Rmb110.60bn.

General manufacturing industries can afford the costs of achieving carbon neutrality. Energy accounts for a relatively low proportion of total cost in general manufacturing industries. According to the previous calculations, if green energy is used to replace fossil energy, the cost of achieving carbon neutrality in the general manufacturing industry is Rmb110.6bn, equivalent to only about 3% of the industry's profit in 2019.

7.6.2 Technology Roadmap for Carbon Emissions Reduction in General Manufacturing Industries

Carbon emissions in general manufacturing industries mainly come from electricity consumption and metallurgy. In term of electricity consumption, the most suitable way to reduce carbon emissions is to reduce energy use by improving production efficiency. In term of metallurgy, the main way to reduce carbon emissions is to increase the proportion of electrification and improve the original production methods.

Digital transformation can improve production efficiency. Increasing digitization of production equipment and penetration rate of industrial software can help improve production efficiency and energy utilization of manufacturers.

Electric motor systems consume about 75% of industrial electricity, and high-efficiency motors and variable frequency equipment can significantly reduce energy use. High-efficiency motors can reduce energy use by about 20% on average and variable frequency technology can help cut electricity uses by 30%.

The main source of carbon emissions in metal casting is the smelting copula, for which production is responsible for 53% of carbon emissions. Through improvements in the casting production process, we think energy consumption per unit of finished product can be reduced by 63.6%.[2]

Through lightweight and modular design of products, raw materials and energy consumption may be reduced. Equipment refurbishment can also help reduce waste of raw materials, energy use, and carbon emissions.

In term of policy, subsidies can promote the use of new technologies, but require standards and supervision. Complicated subsidy application procedures, loose market regulation, and poorly-designed evaluation standards might have the opposite effect.

Most Chinese general manufacturing companies are small businesses with low profitability. In addition, there are significant differences across different industries. Subsidies and regulation need to be different for different industries and different profit levels.

7.6.3 Lowering the Green Premium: The Feasible Pathway to Achieving Carbon Neutrality in the General Manufacturing Industry

The general manufacturing industry already reached peak carbon emissions in 2010 and should achieve carbon neutrality before 2060. According to CAEDs, carbon emissions from general manufacturing industries peaked at 392mn tonnes in 2010. Since then, this figure has been falling year-over-year, with 2017 carbon emissions

[2] Analysis on Status Quo of Energy Saving and Emission Reduction in the Foundry Industry by Li Yuanyuan et al., 2010.

Table 7.2 Current Green Premium for General Manufacturing Industries[3]

Energy cost of general manufacturing industries (Rmb bn)	2019	Cost after carbon neutrality (2019)	2030	Cost after carbon neutrality (2030)	2060	Cost after carbon neutrality (2060)
Electricity	118	132	161	161	234	234
Coke	22	74	34	53	104	104
Natural gas	31	31	53	53	147	147
Diesel	18	45	27	32	64	64
Gasoline	17	35	25	25	49	49
Total	206	317	301	325	598	598
Green premium		111		24		0

Source CEADs, CICC Research

being 40% lower than the 2010 level. Taking into account the proportion of green electricity, electrification rate of vehicles, the proportion of metallurgical electric furnaces, utilization rate of hydrogen energy, China's economic growth, and energy-saving technological advancements, we expect general manufacturing industries to achieve carbon neutrality before 2060.

Our calculation shows that the green premiums for general manufacturing industries would be Rmb110.6bn, Rmb24.1bn. and Rmb0 in 2019, 2030, and 2060 respectively (see Table 7.2). The main reasons for this decline are electrification of vehicles and falling cost of renewable energy sources and hydrogen.

[3] The current green premium for general manufacturing industries is Rmb110.60bn.

Chapter 8
Green Transportation: A Challenging Road to Carbon Neutrality

Abstract Chinese transportation industry: Carbon emissions under upward pressure and "green premium" may stay high.

Transportation industry is of vital importance to social development. International Energy Agency (IEA) data indicates that the transportation sector contributed 9.7% of China's carbon emissions in 2018,[1] 5ppt higher than that in 1990. As GDP per capita rises, we expect the turnover rate of the transportation volume in 2060 to double, leading to a significant rise in carbon emissions in the near future.

In addition, we expect the "green premium" (i.e. the additional cost of choosing a clean energy over one that emits a greater amount of greenhouse gases like fossil fuels) of the transportation sector to be 68% in 2021, implying the cost of zero carbon emissions (i.e. the difference between the cost of using new energy and the cost of using fossil fuels) at about Rmb2.7trn, which indicates the process of decarbonization would be costly and challenging. In this chapter, we focus on the solution to China's green transportation, and aim to deduce a feasible pathway for the transportation industry to achieve carbon neutrality, potential challenges we might face, and supportive policies that are throughout the process.

Green transportation requires a combination of clean energy adoption and efficient energy consumption. While adopting clean energy is the key solution, energy conservation and emissions reduction would also help the transportation industry achieve carbon neutrality. Under neutral assumptions, we believe carbon emissions of the transportation sector will peak at 1.33bn tonnes in 2030 and decline 77% from 1.16bn tonnes in 2019 to 261mn tonnes in 2060.

From a sub-sector perspective, the pathway to carbon neutrality is very clear for the segment of transportation by passenger vehicles[2], we believe this segment is likely to make substantial progress in emissions reduction with China's competitive advantage in lithium-ion batteries. The segment of transportation by commercial

[1] There are differences in the statistics of carbon emissions from transportation industry in various databases. In previous chapters we cite data from CEADs which is lower than the carbon emissions data of the International Energy Agency and the "Second Two-Year Update on Climate Change of the People's Republic of China". We refer to data from IEA in this chapter for the purpose of international comparison.

[2] Passenger vehicles in this chapter refer to private cars.

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_8

vehicles[3] sector is likely to achieve carbon neutrality by 2060 by relying on mid- and mini-electric trucks as well as heavy-duty fuel cell trucks. The railway transportation sector provides a clear vision for decarbonization by means of electrification. Yet it is more challenging to achieve carbon neutrality for the air and marine transportation segments, which heavily depends on technology advancement.

We will also discuss the potential technological evolution in automotive batteries and hydrogen fuel cells. In terms of technological advancements, the former has a promising pathway, whereas hydrogen fuel cell may develop beyond or under our expectations. In addition to technology advancement, achieving carbon neutrality for the transportation sector also requires policy intervention. We will give policy recommendations from both the industry level (such as separation of vehicle and battery) and technology level (such as establishing standards for hydrogen fuel cells).

The "green premium" of the transportation sector is likely to reach 2% in both 2030 and 2060, with "zero emission costs" of Rmb89.7bn and Rmb70.1bn, 97% lower than that in 2021, indicating the viability of such emissions-reduction pathways.

Finally, we will briefly discuss the changes that autonomous driving, super-high-speed rail and supersonic aircraft might bring to our lives. In an era of rapid technological change, we look forward to the arrival of "green transportation".

8.1 How Far Away is Green Transportation?

To reach the Paris Agreement's goal of capping the rise of global temperature under 1.5°C degrees requires extensive global cooperation to reduce carbon emissions. As the world's second largest carbon emitter among all industries needs to be more environmentally friendly. Before moving on to discuss how to achieve the ultimate goal of green transportation, the industry's current performance and historical development will be discussed in this section descibed first. We further discuss the following issues in this section: (1) sources of carbon emissions in the transportation industry; (2) current volume of carbon emissions from global transportation, and emissions structure by country and transportation segments; and (3) prediction of carbon emissions trend in the Chinese transportation industry based on past experience from the US and Europe.

8.1.1 Sources of Carbon Emissions in the Transportation Industry

Steam engines were invented during the first Industrial Revolution and were used for marine and rail transportation in the early nineteenth century, signaling the start of carbon emissions in the transportation industry. The internal combustion engines

[3] In this chapter, commercial vehicles (CV) refer to trucks unless stated otherwise.

invented during the second Industrial Revolution led to the emergence of cars in 1887 and airplanes in 1903, accelerating carbon emissions in the transportation industry. Subsequently, improved transport infrastructure made transportation and travel more convenient. For example, the total length of railways around the world has increased by about 600,000km over the past century, which is nearly double the length in the previous century, and the global ownership of aircrafts for aviation expanded from zero to about 450,000 at present. The market for transportation via roads, aviation, rail and marine has entered the era of all-round development, which has led to a large amount of carbon emissions.

8.1.2 Current Amount of Global Carbon Emissions from Transportation

IEA data shows that the world emitted 33.5bn tonnes of carbon in 2018 (+63% from 1990), with 24.6% or 8.26bn tonnes from the transportation industry (Fig. 8.1), second only to the power generation industry (41.7%). Moreover, the 24.6% proportion expanded 2.2 ppt from 1990, as carbon emissions from the transportation industry rose at a 2.1% CAGR over 1990–2018, exceeding the 1.8% CAGR of overall global emissions.

This section will analyze changes in global carbon emissions within the transportation industry, by segment and country (starting from 2008 due to data availability).

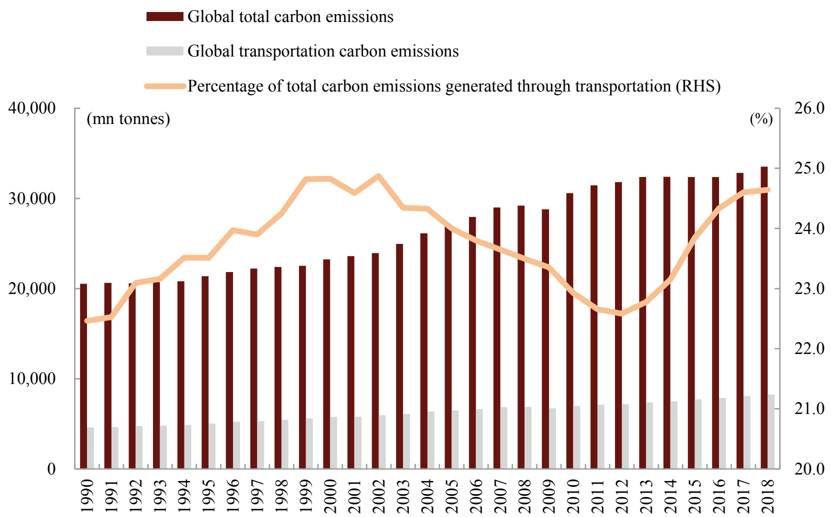


Fig. 8.1 Global carbon emissions from transportation. *Source* IEA, CICC Research

8.1.2.1 Type of Transportation: Road Transport is the Largest Source of Emissions, While Aviation's Emission Volume Growth is the Highest

Total emissions volume: In 2018, road transport emitted 6.1bn tonnes of carbon, accounting for 74.5% of global emissions from the transportation industry. The share of aviation and marine transportation stood at 11.7% and 10.5%, while the proportion of railway transportation was only 1.1% due to the wide adoption of electrification.

Incremental emissions volume: The world's incremental carbon emissions from transportation totaled 1.4bn tonnes in 2008–2018, with 78% or 1.1bn tonnes from road transportation. Carbon emissions from aviation recorded the highest growth among all modes of transport—expanding at a 3.4% CAGR in 2008–2018 and increasing about 200mn tonnes in 2008–2018—and accounted for 14% of the global incremental emissions from transportation. The world's aviation passenger turnover rate increased at a 5.9% CAGR, which is a major driver for the growth in carbon emissions from aviation.

8.1.2.2 Countries: US Contributed Most to Global Carbon Emissions from Transportation, while Emissions from Chinese Transportation Industry Had the Highest Growth

Total carbon emissions volume: The transportation industry in the US, EU and China emitted 1.81bn, 1.24bn and 1.12bn tonnes of carbon respectively in 2018, accounting for 21.9%, 15.0% and 13.6% of global emissions from transportation.

Incremental emissions volume: Carbon emissions from transportation in China had the highest growth rate, while emissions from transportation in the EU and the US trended downward. Carbon emissions from transportation in China increased 580mn tonnes in 2008–2018, accounting for 41% of global incremental emissions. Of the 580mn tonnes, 88% or 510mn tonnes were from road transport, as Chinese personal vehicle (PV) ownership surged 557% YoY and road cargo turnover soared 177% YoY during 2008–2018. In contrast, carbon emissions of transportation in the EU and the US in 2018 contracted about 68mn and 200mn tonnes from 2008, implying a CAGR of –0.2% and –1.1%.

8.1.3 Have Carbon Emissions from Transportation Peaked in EU and US? What Experiences Can China Draw upon?

Carbon emissions from transportation have not yet peaked EU and US. The emissions from transportation declined after hitting highs of 1.3bn tonnes in the EU and 2bn tonnes in the US in 2007. However, the emissions in both EU and US rebounded later. According to the latest available data, carbon emissions from transportation in EU and US both recovered to more than 90% of their respective highs seen in 2007. Whether the emissions have peaked still depends on the adoption rate of new energy.

8.1.3.1 Experiences that China May Draw upon from the EU and US

First, we do not think the transportation industry can reach peak carbon emissions unless emissions from road transportation have peaked. In 2018, road transportation contributed 86% and 72% of the total transportation sector's carbon emissions in the US and EU. Emissions in these two regions both temporarily peaked after road transportation's emissions peaked.

Second, the transport turnover trend largely moves in tandem with carbon emissions. As mentioned earlier, after peaking temporarily, the emissions from transportation in EU and US declined at first and then picked up again. Partially it is driven by the fact that both cargo and passenger transport turnover contracted after the financial crisis in 2007 and did not grow again until 2013 when the economies started to recover. In other words, transport turnover plays an important role in affecting the total carbon emission from transportation.

Third, the decline in carbon emissions from transportation relies on the enhancement in energy consumption efficiency, and the application of new energy and new technologies can also accelerate the enhancement. We noticed that per-unit energy consumption of each mode of transportation declined at an accelerated pace in both the US and EU after 2007. For example, per-unit energy consumption in the US PV-based transport sector dropped 1.1% in a decade after 2007, faster than the 0.6% decline seen in the decade before 2007. This trend, to a large extent, is driven by applications of new energy and new technologies.

8.2 The Difficulties for Chinese Transportation Industry to Achieve Carbon Neutrality Measured by the "Green Premium"

This section focuses on carbon emissions from the Chinese transportation industry, and uses the "green premium" to calculate the cost of zero carbon emissions for it. We notice that carbon emissions from transportation might rise notably in China, and the high "green premium" indicates the industry faces great difficulties in achieving carbon neutrality.

8.2.1 Carbon Emissions from Transportation Rise Notably in China

In 2018, IEA data shows that transportation contributed 9.7% of China's carbon emissions (see Fig. 8.2), still well below the global share of 24.6%. Nevertheless, carbon emissions from transportation expanded at an 8.3% CAGR in China during 1990–2018, much higher than the 2.1% growth of global emissions from transportation and the 5.6% growth of China's total carbon emissions. The share of carbon emissions from transportation in China expanded 5ppt in this period. As GDP per capita rises, transportation demand is expected to grow faster and the total carbon emissions of transportation will increase notably in China. It remains unclear when the country's transportation industry will achieve carbon neutrality. However, the predicting timetable by analyzing its carbon emission structure and emission growth drivers in each sector.

Road transport, aviation, marine transportation, and railways contributed 83.4%, 9.8%, 5.4% and 1.3% of China's total carbon emissions from transportation in 2018 (see Fig. 8.3). Based on the experience in the US and Europe, we will focus on road transportation and aviation sectors when analyzing emissions from the Chinese transportation industry.

There are two sub-sectors of the road transportation: PV-based transport and CV-based transport.

The rising PV ownership and the penetration of alternative fuel vehicles strongly influence the amount of carbon emission of the PV-based transportation. In China,

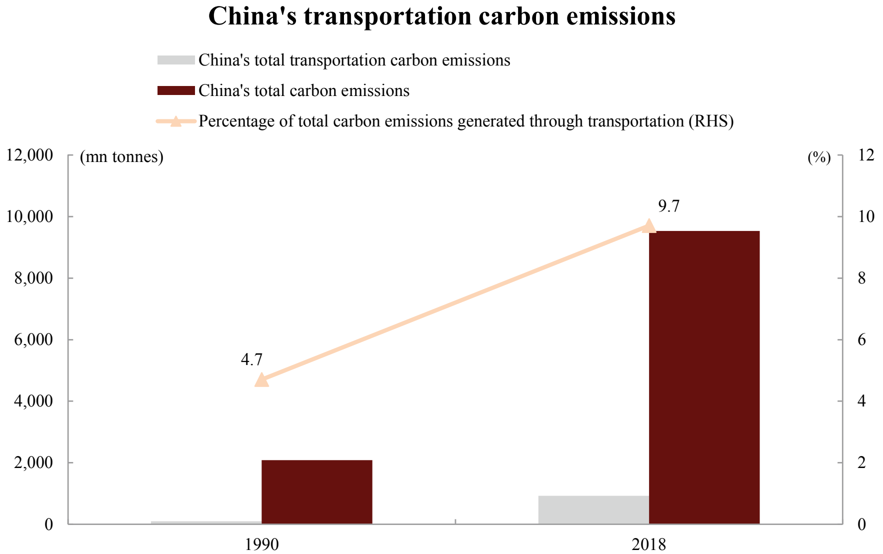


Fig. 8.2 Carbon emissions from transportation in China. *Source* IEA, CICC Research

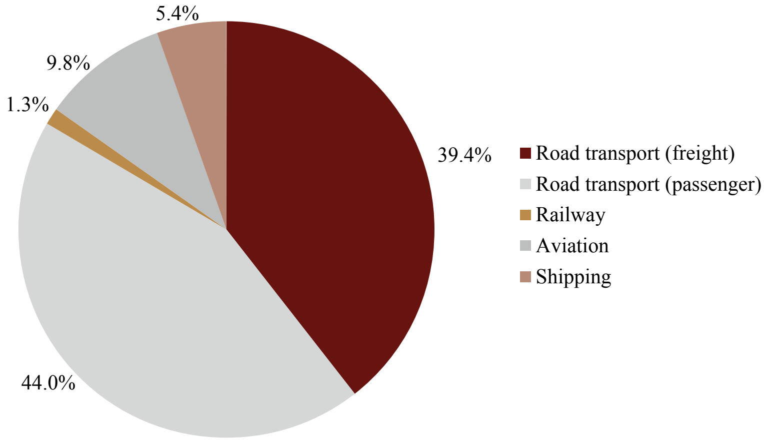


Fig. 8.3 Chinese transportation industry's emissions structure in 2018. *Source* IEA, CICC Research

the PV ownership still has large upside potential. Wind Info data shows that the ownership per 1,000 persons in China was only about 1/6 and 1/5 of the levels in the US and Europe in 2019. Meanwhile, China leads the world in NEVs. We believe the rising NEV penetration and increasing PV ownership will both affect the country's PV-based transport carbon emission.

The changes to freight transport structure and the timing of mass adoption of alternative fuel CVs hold the key to the carbon emissions from CV-based transport. In our view, alternative fuel CVs will first enter the market with light-duty trucks, then mid-duty trucks, and eventually heavy-duty trucks, to gradually reduce carbon emissions of CV-based transport. We believe China's freight transport structure will change as freight owners shift away from road transport to railway and waterway. In addition, efforts in energy saving and emissions reduction such as improving fuel efficiency and digitalization applications are equally important before massive penetration of alternative fuel CVs.

The aviation sector also merits attention. It is the second largest carbon emitter in the transportation industry, and its emission growth remains high. Decarbonization of the aviation sector is challenging, and the key lies in jet fuel replacement by new energy. We predict aviation transport volume will continue to grow. Wind Info data shows that the number of per-capita air trips in China was only 1/7 and 1/5 of the levels in the US and EU in 2018. Due to its long transporting distance, heavy energy consumption and immature zero-carbon technologies, decarbonization in the aviation sector is challenging.

The marine transportation sector faces challenges down its road to decarbonization. It contributed only 5.4% of carbon emissions from the transportation industry in 2018, and its emissions CAGR remained low at 1.4% in the past decade. However, decarbonization is challenging due to long transport distance and high vessel tonnage.

The railway sector faces a visible pathway of decarbonization via electrification. Electrification rate in this sector expanded 36ppt in the past decade to reach 72%.

We believe the railway sector will achieve zero carbon emissions if electrification system is fully adopted.

8.2.2 The High "Green Premium" Indicates Decarbonization in the Transportation Industry Is Costly and Challenging, and Requires a Combination of Technological Innovation and Favorable Policies

As mentioned earlier, the "green premium" refers to the additional cost arising from using new energy as a percentage of the cost of using fossil fuels, and the cost of zero carbon emissions is the additional cost that needs to be paid to achieve zero carbon emissions.

Take PV-based transport an example. The "green premium" in the PV-based transport sector is defined as follows: (clean electricity cost–gasoline cost)/gasoline cost. We estimate that PV's clean electricity cost per 100 km is 60% lower than that of gasoline cost in 2021. However, as pure electric PVs are more expensive than traditional fuel PVs, we think calculating based on lifecycle cost is more reasonable. Assuming similar specifications and torque, we estimate that the lifecycle cost of a traditional fuel PV is about Rmb0.57/km, versus Rmb0.68/km of a pure electric PV. The PV industry's energy consumption cost will increase from Rmb2.3trillion at present to Rmb2.7trillion after traditional fuel PVs are completely replaced. In other words, the "green premium" is about 18%. For more details, please refer to Table 8.1.

The "green premium" of the aviation sector is defined as (hydrogen cost–jet fuel cost)/jet fuel cost. Although calculation based on lifecycle cost is more reasonable,

Table 8.1 We estimate that the transportation industry's "green premium" in 2021 is around 68%

2021E	Current energy cost (Rmb bn)	Alternative energy cost (Rmb bn)	Zero carbon emission cost (Rmb bn)	Green premium (%)
Road transport (freight)	1,519	3,454	1,935	127
Road transport (passenger)	2,267	2,685	418	18
Railway	41	29	–12	–29
Aviation	72	317	245	343
Shipping	28	116	88	319
Total	3,926	6,601	2,675	68

Note We calculate zero carbon emission cost of PV- and CV-based transport sectors based on lifecycle cost. *Source* CICC Research the "green premium" is calculated with only energy consumption cost, given unavailable data on the cost of newly or renovated hydrogen-powered planes. We calculate the "green premium" is 343%, with total jet fuel cost at Rmb71.5bn and hydrogen consumption cost at Rmb316.7bn.

Generally speaking, the transportation industry's zero carbon emission cost in 2021 is estimated to be around Rmb2.7trn, implying a "green premium" of 68%, which suggests a high cost from carbon neutrality. The energy consumption cost from transportation is about Rmb3.9trn in 2021. The total cost of new energy would be about Rmb6.6trn, assuming all HDTs are powered by hydrogen, and MDTs, LDTs, PVs and trains all by clean electricity. As such, the zero carbon emission cost for the transportation industry is around Rmb2.7trn in 2021, implying a "green premium" of 68%.

Overall, the road to carbon neutrality is costly and challenging for the transportation industry. For transportation, achieving carbon neutrality requires a combination of technological innovation and policy support. The next three sections will discuss the carbon emissions trend in the transportation industry, potential technological innovations, and public policy support.

8.3 Viable Options for China to Achieve Green Transportation

In previous sections we discussed carbon emissions from transportation in China, and analyzed difficulties for the industry to achieve carbon neutrality by calculating green premium. This section will mainly discuss the pathway of carbon emissions reduction. Carbon emissions of the transportation industry will be calculated, followed by the prediction of emissions from each transportation subsector. Specifically, transport turnover rate and ownership in the next 4 decades will be predicted, carbon emissions based on the forecasts will be calculated and assumptions on penetration of new energy and per-unit energy consumption will be made. Last but not least, specific options on decarbonization shall be provided.

8.3.1 Carbon Emissions from the Transportation Industry: Emission Peak in 2030; Carbon Neutrality in 2060 Seems Unlikely Under a Neutral Assumption that Emissions in 2060 Equal 23% of the Level in 2019

8.3.1.1 Transport Turnover in 2060 to Double the Level of 2019

Turnover rate (i.e. tonnes-km) can measure carbon emissions more effectively than freight or passenger traffic volume. The transportation industry's turnover reached

19.7trn tonnes-km in 2019, and may rise to 38.7trn tonnes-km in 2060, implying a 1.7% CAGR in 4 decades.[4]

We expect turnover growth in the next 4 decades to be 0.6%, 3.5%, 1.8% and 2.4% for road transport, aviation, marine transport and railway respectively (see Table 8.2). For road transport, expected turnover growth is the lowest as high-speed trains and airlines will divert passenger traffic and certain cargo owners may shift away from road transport to railway or waterway. In comparison, aviation sector is expected to

Table 8.2 Our forecasts for transport turnover in 2060

Transportation turnover	2019	2060E	2060E versus 2019 (%)	CAGR (%)	Assumption
Total (bn tonne-km)	197,164	387,418	196	1.7	
By transport					
Road transport	60,425	78,408	130	0.6	We believe a portion of highway transportation will continuously be taken away by high-speed rails and aviation; compared to those prior to 2019, growth rate of freight transportation on highways will slow down driven by traffic taken away by railways
Aviation	1,293	5,393	417	3.5	Based on the case of the US, CAGR of aviation turnover is around 5% if GDP per capita is US$10,000–20,000; CAGR of aviation turnover is around 4% if GDP per capita is US$20,000–30,000; CAGR of aviation turnover is around 2% if GDP per capita is US$30,000–40,000

(continued)

[4] The Ministry of Transport's statistics on road passenger turnover do not include transportation by PVs. However, we take it into consideration when calculating carbon emissions.

Table 8.2 (continued)

Transportation turnover	2019	2060E	2060E versus 2019 (%)	CAGR (%)	Assumption
Total (bn tonne-km)	197,164	387,418	196	1.7	
By transport					
Shipping	103,970	219,094	211	1.8	Driven by internal circulation of the economy, we believe CAGR of transportation turnover of inland rivers is 3.4%, which is higher than that of short seas (2.0%) and that of deep seas (1.0%)
Railway	31,476	84,523	269	2.4	We believe total railway transportation mileage will reach 250,000 km by 2060, 95,000 km of which is on high-speed rails. Also by 2060, the density of China's railway system will be close to that of the US railway system in 2019; passenger transportation will benefit from the increase of total railway mileage; a portion of freight transportation through highways will be replaced by railways

Source Wind Info, CICC Research

record the highest turnover growth driven by rising per capita air trips and low-carbon railway and marine transport will also generate high turnover growth.

8.3.1.2 Under Our Neutral Assumption, We Expect Carbon Emissions from Transportation in 2060 to Plunge 77% from 2019

The transportation industry emitted 1.16bn tonnes of carbon in 2019. Under our neutral assumption, we expect carbon emissions from transportation to peak at 1.33bn tonnes in 2030. The emission will plunge 77% from 2019 to 261mn tonnes in 2060. Unless there are significant technology breakthroughs, we do not think the aviation and marine transportation sectors will achieve decarbonization by 2060. As such, the transportation industry is unlikely to achieve carbon neutrality under neutral assumptions. However, technology advances may give positive shocks, and technological breakthroughs may help the transportation industry achieve carbon neutrality in the next 4 decades.

Overall, carbon emissions in the transportation industry will be affected by the increasing turnover rate, the improvement in fuel efficiency of each type of transport, and the replacement of traditional fossil fuels by low- or zero-carbon energy sources (e.g. applications of electric vehicles, LNG-powered vessels, and biomass jet fuel).

What are the assumptions timing (see Fig. 8.4 and Table 8.3).

The road transport (passenger) sector: Carbon emissions will peak in 2028 when ownership-based penetration rate of NEVs may reach around 10%. The penetration rate of NEVs will rise continuously and reach 100% by 2045, and all PVs will be NEVs thereafter, achieving carbon neutrality in 2060.

The road transport (freight) sector: Carbon emissions will peak in 2030 when ownership-based penetration rate of alternative-fuel trucks may reach around 10%. In our view, the ownership-based penetration rate of electric MDT, LDT, and mini trucks will rise to 100% in 2050, and the rate of fuel cell-powered HDTs will reach

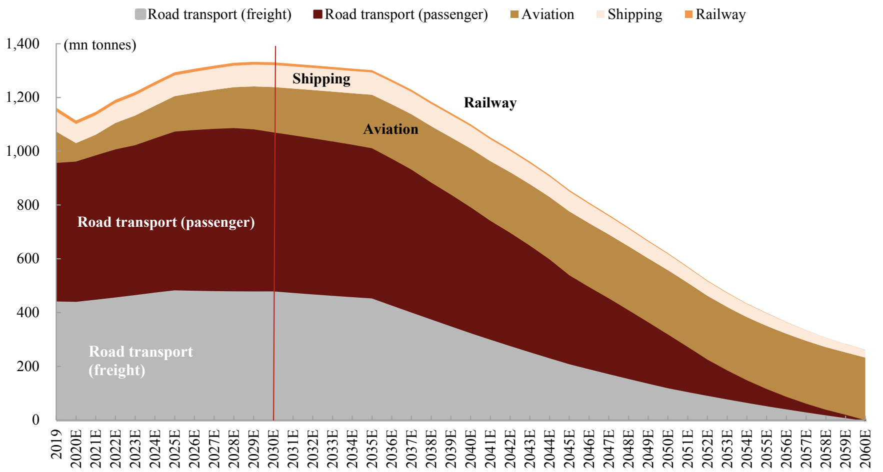


Fig. 8.4 Our forecasts for carbon emissions from transportation in 2020–2060. *Note* The red line indicates the timing that the transportation industry will reach peak carbon emissions. *Source* IEA, CICC Research

Table 8.3 Major timing of carbon emissions from transportation sectors and our assumptions

Timeline	2025E	2028E	2030E	2040E	2045E	2050E	2060E
Key events related to carbon emissions		Carbon peak for passenger cars	Carbon peak for highways	Carbon peak for shipping		Carbon peak for aviation	Carbon neutrality for highways and railways
Road transport (passenger)	BEV achieves purchase parity compared with traditional fuel vehicles, and the penetration rate of new green-cars reaches 20%	1) The penetration rate of green-cars reaches 10% by 2028 2) The car parc per 1,000 people reaches approximately 250			1) The car parc per 1,000 people will reach 500, and autonomous driving will spread, after which the car parc will begin to decline. 2) The penetration rate of new green vehicles reaches 100%.		100% green for passenger cars
Road transport (freight)	1) The penetration rate of green medium and light trucks will reach 3% 2) The penetration rate of FCEV heavy trucks will reach 1%		1) The penetration rate of green medium and light trucks will reach 20% 2) The penetration rate of FCEV heavy trucks will reach 3%	1) The penetration rate of green medium and light trucks will reach 70% 2) The penetration rate of FCEV heavy trucks will reach 30%		The penetration rate of green medium and light trucks will reach 100%	The penetration rate of grean heavy trucks will reach 100%
Aviation			Biomass fuel will start to supply energy, accounting for 1%	Hydrogen aircraft will enter the market		Biomass fuel and hydrogen will supply 25% of energy	Biomass fuel and hydrogen will supply 45% of energy
Shipping	1) Penetration rate of inland water electric vessels reaches 1% 2) LNG replaces 3% of shipping fuel		1) Penetration rate of inland water electric vessels reaches 10% 2) LNG replaces 10% of shipping fuel				1) Fully electrified inland watercraft 2) LNG supplies 50% of energy demand, hydrogen energy and ammonia energy each supply 20% of energy demand
Railway	Railway electrification rate reaches 82%		Railway electrification rate reaches 85%	Railway electrification rate reaches 91%	Railway electrification rate reaches 94%	Railway electrification rate reaches 96%	Railway electrification rate reaches 100%

Source CICC Research

100% in 2060. In other words, we think the CV-based transport sector will reach carbon neutrality in 2060.

The aviation sector: Emission peak will be reached in 2050. In our view, the penetration of biomass fuel and hydrogen energy in airplanes will rise to 25% in 2050, and then rise gradually, but cannot completely replace traditional jet fuel. We expect the penetration of biomass fuel and hydrogen energy to rise to 30% and 15% in 2060, implying carbon emissions of 232mn tonnes, almost doubling the emissions in 2019 and accounting for 89% of total carbon emissions from transportation.

Marine transportation sector: Carbon emissions will peak in 2040. In our view, the penetration of new energy in this sector will reach 25% in 2040. Although LNG, hydrogen and ammonia will have an increasingly high penetration rate, traditional fuel cannot be completely replaced. Carbon emissions from marine transportation is expected to drop 62% from 2019 to about 29mn tonnes in 2060, accounting for 11% of total carbon emissions from the transportation industry.

Railway sector: Electrification adoption rate will rise to 100% in 2060, helping the railway sector achieve carbon neutrality.

What may go beyond expectation or under expectation? Technology advances and applications of new energy are highly promising for the next 10–15 years. Yet the longer-term technological evolution is unpredictable.

Beyond expectation: (1) The era of intelligent driving is likely to arrive earlier than expected: When the era arrives, vehicle ownership may largely shrink and the PV-based transport sector may achieve carbon neutrality earlier than 2060; (2) fuel efficiency improvement might beat expectations: If carbon trading market matures, this may encourage companies to accelerate energy conservation and emissions reduction, leading to a positive fuel efficiency enhancement; and (3) technologies on hydrogen energy are likely to beat expectations, given recent breakthroughs in hydrogen storage technology.[5]

Under expectation: (1) penetration rate of new energy in CV-based transport sector is slower than expected: As trucks are mostly owned by individuals that focus more on returns, we believe the penetration rate could be slower than expected before price parity is achieved; and (2) applications of biomass fuel in airplanes missing expectations: The applications require a sound biomass value chain, but collection and conversion of biomass raw materials are both challenging. As such, we believe the applications may miss expectations.

Optimistic and pessimistic scenarios on the transportation industry's carbon emissions roadmap are examined as follows (see Fig. 8.5): For the optimistic scenario, carbon emissions from transportation will peak in 2028 at 1.27bn tonnes (earlier than expected), and transportation will achieve zero carbon emissions in 2060. For the pessimistic scenario, we expect the emissions from transportation to peak at 1.44bn tonnes in 2035 and drop only 48% from 2019 to 610mn tonnes in 2060.

In the next part, we focus on individual transportation sectors. We first discuss each sector's current emissions, predict future ownership, turnover and emissions in 2060, and then propose specific emissions-reduction options.

8.3.2 The PV-Based Transport Sector: PV Ownership to Rise at First and then Decline; Zero Carbon Emissions to Be Achieved in 2060

8.3.2.1 PV Ownership to Rise First, then Decline, and Reach 531mn Units in 2060, Rising 158% from 2019

China's PV ownership is expected to experience three periods:

Period I: From now to 2030. The Chinese economy will undergo mid- or high-growth momentum and rising GDP per capita will lead to strong growth in PV ownership per 1,000 persons. China's PV ownership will expand from 210mn units in 2019 to 432mn units in 2030, in our view implying a 6.9% CAGR.

Period II: From 2030 to 2045. During the second period, the Chinese economy will reach a mature stage which GDP per capita will maintain at a mid- or low-growth momentum level, and growth of PV ownership per 1,000 persons will decelerate. China's PV ownership per 1,000 people in the longer term will be similar to levels in Japan and South Korea, and reach 500 units in 2045, still lower than the 800 units in the US. Chinese PV ownership will peak at 710mn in 2045, implying a 3.3% CAGR.

Period III: From 2045 to 2060. In the third period, intelligent driving and traffic will effectively enhance transport efficiency, and hence reduce PV demand and drive

[5] Balancing volumetric and gravimetric uptake in highly porous materials for clean energy, written by CHEN Zhijie Chen and LI Penghao, published in Science in April 17, 2020.

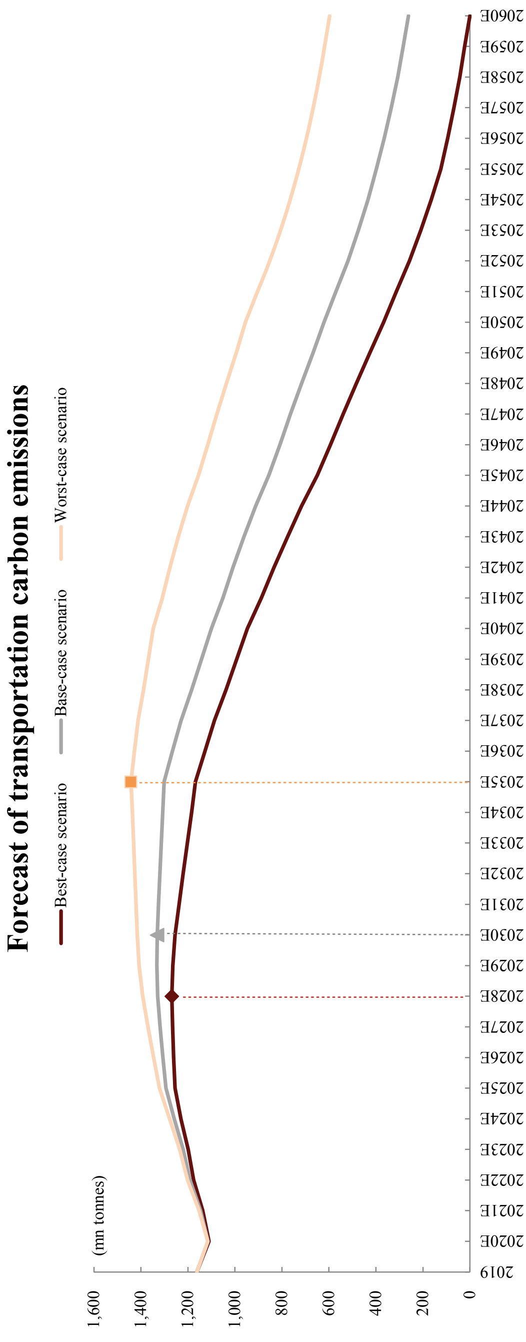


Fig. 8.5 Our forecasts for carbon emissions from transportation in 2020–2060 under three scenarios. *Note* The marks in this chart indicate the timing of peak carbon emissions. *Source* IEA, CICC Research

down PV ownership. Thus, China's PV ownership may drop to 531mn units in 2060, in our view implying a –1.9% CAGR in 2045–2060.

8.3.2.2 NEV Sales Volume Forecast: We Expect Alternative-Fuel PVs to Achieve a Purchase Price Parity in 2025 and Their Penetration Rate (Based on Sales) to Reach 100% in 2045

Given the expected PV ownership, alternative fuel vehicle's penetration rate can be used as the most important factor when calculating carbon emissions. Installation cost of ternary battery packs in 2025 is likely to decline 35% from 2020 due to clear economies of scale and lower cost of LIB materials. This drop in cost should help pure electric vehicles achieve purchase price parity with traditional fuel vehicles, thus further driving up the penetration rate of pure electric vehicles. Alternative-fuel PVs had a penetration rate of 6.2% in 2020 (based on sales volume). Penetration rate is likely to reach 20% in 2025, 50% in 2035, and 100% in 2045, given China's NEV industry blueprint for 2021–2035 and a technological roadmap for NEV and energy conservation.

We expect the PV-based transport sector to reach peak carbon emissions in 2028, given our forecasts for new energy vehicle penetration and energy conservation of traditional fuel vehicles. Based on our estimation, traditional fuel PVs will be all scrapped in 2060, and the PV-based transport sector will achieve zero carbon emissions.

8.3.2.3 Energy Conservation and Emissions Reduction in the PV-Based Transport Sector Requires a Combination of Multiple Factors

The technical pathways for the PV-based transport sector to acheive carbon neutrality mainly rely on energy conservation of traditional fuel vehicles and the use of clean energy. The next section will closely examine three different pathways: light materials, hybrid power, and LIB. The light material pathway is the least effective in emissions reduction, while the LIB option is the most effective.

The light material pathway can reduce the weight of a vehicle by 35% in 2030 compared with 2015. The light material pathway refers to the application of aluminum alloy, magnesium alloy and carbon fiber reinforced materials. According to a study made by European Automobile Manufacturers Association, a 100kg decline in a vehicle's weight can reduce oil consumption per 100km and carbon emissions by 0.4L and 1kg. We noticed that aluminum consumption per vehicle in the US and Europe increased steadily and both exceeded 180kg in 2020. In contrast, the amount in China was only 105kg in 2017, pointing to large upside. We expect the average vehicle weight in China in 2030 to decline 35% from 2015.

The hybrid power pathway is the best emissions-reduction option before NEVs completely replace traditional fuel vehicles. China Society of Automotive Engineers released a document on technological roadmap 2.0 for energy conservation and NEVs. According to this document, penetration rate of new hybrid vehicles may reach 50% in 2035 and hybrid vehicles could begin to completely replace traditional fuel vehicles. Hybrid vehicles are driven by both engines and electric motors, which can help engines work efficiently under different road conditions.

China's domestic automakers have developed hybrid power technologies. For example, SAIC Motor, Guangzhou Automobile Group, Great Wall Motor, Geely, and BYD have all released their hybrid power development platforms to better cope with increasingly tight oil consumption standard.

Mass LIB production is of great importance to carbon neutrality in the PV-based transport sector. NEVs still have significant disadvantages in comprehensive performance and driving experience. For example, their driving range declines considerably when the temperature is low, and hot weather tends to trigger thermal runaway in battery packs, raising strong consumer concerns on driving range and safety. LIB producers and automakers both play an important role in resolving such challenges.

LIB producers will settle technological constraints by optimizing battery material system and developing new cell technologies. We believe these efforts will quell consumer concerns on driving range to some extent and pave the way for NEVs to completely replace traditional fuel vehicles in 2045.[6]

Emerging automakers began to work on vehicle intelligence, innovate business models, and improve driving experience. For example, Tesla has promoted fast charging technology, enlarging the maximum charging power to 250kW, which can meet consumer needs for charging time. In addition, we think rising penetration of smart electric vehicles will push consumers to shift away from traditional fuel vehicles to NEVs. Compared with its 1.0 platform, NIO's pilot 2.0 platform has significantly improved performance of smart electric vehicles in aspects such as algorithm, computing power, and hardware products.

8.3.3 Carbon Emissions from CV-Based Transport Sector: Rising Applications of New Energy, Digitalization Technology and Changing Transport Structure to help this sector achieve carbon neutrality in 2060

8.3.3.1 Changing Freight Transport Structure to Reduce Demand for Road Freight Transportation

After analyzing freight transport structure in the US and EU, we found that the structure is dominated by waterway in the EU and by railway in the US. These two regions have been less reliant on road transportation, whereas the exposure to road transportation is increasing in China.

[6] For detailed analysis, please refer to the technological section on green transportation.

A number of government agencies began to promote switching freight transportation from roads to railways in 2017. The efforts paid off, as railway freight transport volume in 2019 increased about 1.06bn tonnes from 2016. The cost of road transport is twice that of railway transport and is four times that of marine transport. The per-unit energy consumption of road transport is 4 and 10 times that of railway and waterway transport. Furthermore, the shift in the demand for transportation service from roads to railways and marine will continue to divert freight sources and reduce the demand for road freight transport.

8.3.3.2 CV Ownership: HDT Ownership to Peak in 2030; MDT and LDT to Reach Peak Ownership in 2045[7]

HDTs: HDT ownership is expected to rise at first and then trend downward, and it will peak around 2030. Real estate, infrastructure construction, and road-based logistics will continue to boost HDT demand in the coming years. However, HDT demand is likely to decline in the longer term, as cargo owners shift away from road transport to railway and transport efficiency increases. HDT ownership is expected to peak at 10.40mn units in 2030 and drop to 8.17mn units in 2060.

MDT, LDT and mini trucks: Ownership will peak in 2045. The ownership is affected by transport efficiency and road transport demand. According to our estimation, ownership of MDTs, LDTs and mini trucks will rise in the medium and long term driven by increasing urbanization rate, and then peak in 2045. Subsequently, the ownership of these subsectors will start to shrink as autonomous driving dominates the CV market. In addition, we think coach ownership has peaked and will remain stable in the long term.

8.3.3.3 New Energy Vehicles Are Expected to Fully Replace Traditional Fuel Vehicles in 2060, Helping the CV-Based Transport Sector Achieve Carbon Neutrality

The penetration rate will reach 100% in 2030 for alternative-fuel coaches, in 2050 for new-energy MDTs, LDTs and mini trucks, and in 2060 for alternative-energy HDTs. In other words, we think the CV-based transport sector will achieve carbon neutrality in 2060.

Alternative-fuel coaches will completely replace traditional coaches in 2030 as local governments buy a growing number of pure electric coaches.

The penetration rate of electric LDTs, MDTs and mini trucks will rise to 100% around 2050.

The rising penetration rate of fuel cell-powered HDTs depends on policy support and the magnitude of reduction in fuel cell cost. According to the technological

[7] HDT, MDT, and LDT refer to heavy duty truck, medium duty truck, and light duty truck, respectively.

roadmap 2.0 on NEVs and energy conservation, the ownership of fuel cell-powered CVs may rise to around 1mn units in 2035, implying a penetration rate of about 8%. As fuel cells generate electricity more efficiently and hydrogen storage technologies improve, hydrogen fuel cells will be widely used in HDTs, and fuel cell HDTs will fully replace traditional fuel HDTs in 2060.

The options on energy conservation and emissions reduction in the CV-based transport sector are listed as follows:

Option I: Hydrogen fuel cells replacing traditional fuel.

Using hydrogen fuel cells becomes an important option for the CV-based transport sector to save energy and reduce emissions because of their extensive raw material sources and they are also more environmentally friendly. Hydrogen fuel cells have a definite technological direction, but the development of such technologies is still in its infancy. More details are provided in the next section.

Option II: A combination of power unit technology and exhaust gas after treatment technology.

In the past decade, China has repeatedly upgraded its emissions standard on internal combustion engines, and each upgrade is associated with the release of stricter emissions requirements. For example, under the China VI emissions standard for HDTs (effective in July 2021), the emissions cap on hydrocarbon and carbon monoxide is only half the level under the China V standard, and the limit on particulate matters is 1/10 of the specified number in the previous standard. China will continue to upgrade the emissions standard and launch China VII standard in the next decade which may have stricter requirements for pollutant emissions.

Option III: Digitalization enhances road freight transport efficiency.

Digitalization technology can effectively eliminate agents and settle the problem of freight-truck matching. Specifically, freight-truck matching platforms can reduce the time that truck drivers spend in finding loads and raise matching efficiency by leveraging big data and algorithms based on drivers' locations, habits and routes. According to a report from Sohu,[8] monthly average driving mileage facilitated by Fuyou (a truck-freight matching platform) is 22%–57% higher than the level under traditional dispatching model. Based on transportation data in 2019, we estimate that a 1% decline in the proportion of deadhead trucks can reduce carbon dioxide emissions by about 7.30mn tonnes, accounting for 1.6% of emissions from the CV-based transport sector in 2019.

[8] https://www.sohu.com/a/354965965_168370 (source in Chinese).

8.3.4 The Aviation Sector: Emissions in 2060 to Double from 2019; Achieving Carbon Neutrality is the Most Challenging for All Modes of Transport

This section will first discuss current emissions from the aviation sector, then estimate its turnover rate and emissions in 2060, followed by predicting the emissions-reduction options such as the use of alternative fuel, operation optimization and carbon offsetting and reduction scheme.

8.3.4.1 In the Past Decade, Aviation Turnover Drove High Growth in Carbon Emissions

The aviation sector emitted 117mn tonnes of carbon in 2019 (including international flights), accounting for about 10% of emissions from the transportation industry and implying an 11.5% CAGR in the past decade driven mainly by aviation turnover expansion (an 11.7% CAGR in the past decade).

8.3.4.2 The Aviation Sector is Unlikely to Completely Achieve Decarbonization; Its Carbon Emissions to Double in 2060 Under Neutral Assumptions

There is rising demand for air passenger and freight transportation. In 2019, China's per capita air trips was only 0.4, much lower than levels of 2.2 in the EU and 2.8 in the US. Air passenger and freight traffic in 2060 are expected to be 3.7 and 3.2 times the respective levels in 2019.

In our view, the aviation sector is unlikely to achieve decarbonization completely, and jet fuel replacement by new energy and operation optimization are two options for emissions reduction in this sector. The aviation sector is characterized by heavy energy consumption and long transport distances, posing strong challenges to decarbonization. As such, energy conservation and emissions reduction are of vital importance.

The aviation sector is estimated to emit about 232mn tonnes of carbon in 2060, doubling the emissions in 2019. Assumptions for the above conclusion are as follows: (1) penetration of biomass fuel to rise to 30% in 2060; (2) hydrogen-powered planes to be commercialized in 2040 and have a penetration rate of 15% in 2060; and (3) per-unit fuel consumption efficiency rising 0.5% per annum.

What are the areas that may exceed and fall short of expectations? The part that exceeds expectations: Technological advances tend to exceed expectations, so there is a possibility that hydrogen aircraft will have unprecedented breakthrough. Lower than expected: We believe that the development of biomass fuel oil may be lower than expected, mainly because the collection, transportation and conversion of biomass fuel is difficult to scale.

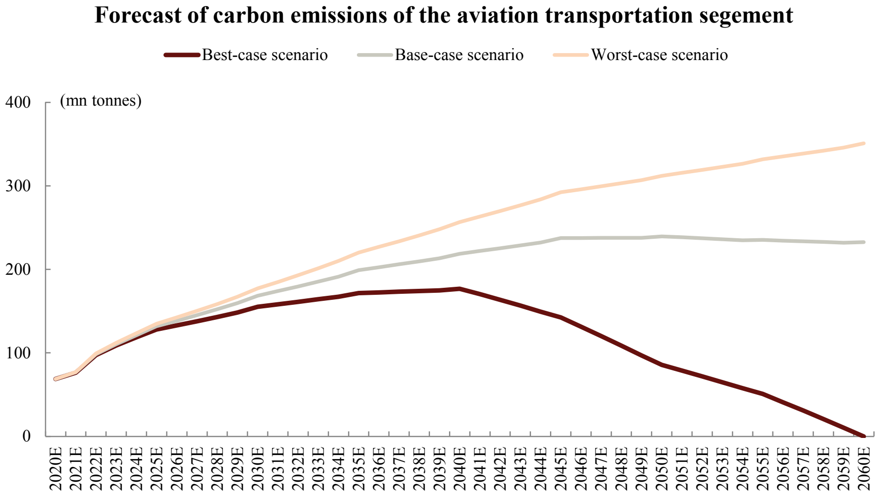


Fig. 8.6 Our scenario analysis and assumptions on carbon emissions from the aviation sector in 2020–2060. *Source* CICC Research

Overall, we expect the aviation sector to achieve carbon neutrality in 2060 under our optimistic scenario. This sector will emit about 351mn tonnes of carbon in 2060 under our pessimistic scenario, tripling the emissions in 2019 (Fig. 8.6).

8.3.4.3 Option 1: Alternative Energy Replacing Traditional Jet Fuel

The alternative energy that is most suitable for airplanes includes biomass fuel, hydrogen energy, and electrical energy. We are relatively upbeat on the applications of biomass fuel after comparing these three energy sources.

The biomass fuel technology is more mature than technologies on hydrogen and electrical energy. China and other countries have produced biomass fuel and applied it to airplanes. For example, the bio-jet fuel made by Sinopec was successfully used in China Eastern Airlines' planes as early as 2013. Moreover, biomass fuel being mixed with existing jet fuel and then used in existing plane engines has been proven feasible.

The application of hydrogen fuel in planes could reshape aircraft architecture. With flying distance being unchanged, the space needed for storing hydrogen fuel is 4–8 times the storage space for traditional fuel. As such, we believe the structure of hydrogen-powered aircraft is very likely to be revamped. Completing the processes of designing, testing and verifying new aircraft normally takes 10–20 years. Therefore, we do not think hydrogen-powered aircraft will be commercialized in the near term.

The weight of batteries may equal or remain lower than maximum take-off weight only when their energy density rises 6–8 times, which is technologically challenging. Thus, pure electric aircraft can only meet requirements for short distance flying.

How much can new energy meet energy demand from aircraft in 2060?

Under neutral assumptions, biomass fuel can meet 30% of energy demand from aircraft. Energy Transitions Commission and Rocky Mountain Institute estimate in a report that China's biomass energy supply potential could be 400–850mn tonnes of standard coal. Given the difficulties in building the biomass value chain, we conservatively assume the potential is 400mn tonnes. Excluding the biomass energy for power generation, chemical material production, and heating for buildings, 40mn tonnes of standard coal (i.e. 10% of the assumed potential) will be used to power aircraft in 2060 under neutral assumptions, accounting for about 30% of jet fuel demand in the same year.

Hydrogen fuel can meet 15% of energy demand from aircraft under the neutral assumption. Hydrogen-powered aircraft are unlikely to be commercialized until 2040 after technological breakthroughs are made. As such, hydrogen fuel can meet 15% of energy demand from aircraft under the neutral assumptions.

We cannot rule out the possibility that other new energy sources (e.g. nuclear energy and solar kerosene) can be used as jet fuel. However, delevopment of relevant technology is still in the early stages. In our view, before new energy replaces traditional jet fuel, improving operations to save fuel consumption[9] is also of great importance to emissions reduction in the aviation sector.

8.3.4.4 Option 2: Improving Operations Can Moderately Reduce Carbon Emissions

Improving operations mainly includes optimization in the flying process, routes and aircraft fleets.

Optimization of flying process: A study made by EUROCONTROL shows that persistent ascending and descending can help aircraft reduce carbon emissions by about 0.6%.

Shortening flying distance: In our view, relying on radar to guide non-stop flights and opening temporary routes can shorten flying distances. For example, China Eastern Airlines' Shanghai-London flight reduced flying distance by 270km by taking similar measures.[10]

In addition to these optimization measures, improving aircraft design and engine thermal efficiency can also reduce carbon emissions. However, China benefits from the potential improvement mainly because it is a buyer of aircraft (the research and development of commercial aircraft might help improve the energy efficiency

[9] We assume 0.5% of jet fuel is saved per year.

[10] http://www.caacnews.com.cn/1/6/201803/t20180312_1242843.html (source in Chinese).

of domestically-made aircraft). Overall, operation optimization can reduce carbon emissions moderately per annum.

Are there any other options if the abovementioned options cannot help the aviation sector completely achieve decarbonization?

8.3.4.5 CORSIA Can Help International Air Transportation Market Achieve Net Zero Carbon Emissions

What is CORSIA?

CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) is a carbon-reduction system that is launched by International Civil Aviation Organization (ICAO) to cover international flights. Under CORSIA, which starts in 2021, airlines buy carbon offset credits to cover any emissions from international flights above the current baseline of average emissions in 2019 so as to achieve zero emissions compared to 2019 level.

China has not participated in CORSIA so far. Its aviation industry may face mounting cost pressure if the country becomes a member. However, this may also help the industry strive to enhance efficiency and reduce cost. We estimate, based on our previous assumptions on turnover and penetration of new energy, that carbon offsetting cost of international flights should be around Rmb8.4–16.8bn in 2060 (assuming carbon price of EUR20–40/tonne). If the cost is passed on to consumers, we estimate this would boost the round-trip ticket of the 4,000km flight between Shanghai and Singapore by 2%–4%. From our point of view, CORSIA may spur the Chinese aviation industry to speed up energy conservation and emissions reduction, amid the high offsetting cost.

8.3.5 Marine Transportation: Carbon Emissions in 2060 to Be 38% of the Emissions in 2019

8.3.5.1 Marine Transportation Accounts for Only a Small Proportion of Total Emissions from the Transportation Industry; Its Emission Growth Remains Slow, and Per-Unit Energy Consumption Has Dropped Rapidly

We estimate marine transportation (including international routes) emitted 74.70mn tonnes of carbon in 2019, accounting for 5.4% of total carbon emissions from the transportation industry and implying a 1.4% CAGR in the past decade. We attribute the slow CAGR to rapid decline in per-unit energy consumption (–31% in 2019 from 2009).

8.3.5.2 Carbon Emissions from Marine Transportation in 2060 to Drop 62% from 2019 Under Neutral Assumptions

We expect marine transportation turnover growth to stay low all the way to 2060 (1.8% CAGR). Replacing traditional fuel with new energy and helping vessels raise energy efficiency are two emissions-reduction options.

The carbon emissions of the marine transportation sector are estimated to contract 62% from 2019 to about 29mn tonnes in 2060. Our assumptions include: (1) all vessels sailing on domestic waterways to be powered by electricity in 2060; (2) ships along coastlines and ocean-going vessels to be powered by diversified energy sources (50% by LNG, 20% by ammonia and 20% by hydrogen energy); and (3) per-unit fuel consumption to fall by an average of 1% per year. The marine transportation sector can achieve carbon neutrality in 2060 under the optimistic scenario, and its carbon emissions in 2060 will drop 20% from 2019 under the pessimistic scenario.

8.3.5.3 Option 1: Clean Energy Replacing Traditional Fuel

Clean energy sources for marine transportation mainly include electricity, ammonia, hydrogen and LNG. We are upbeat on the use of electric ships in domestic waterway transportation. On domestic waterways, transport distance is shorter (about 400 km), and ships have lower deadweight tonnage (around 1,500tonnes), laying a technological foundation for using electricity- or fuel cell-powered ships. For coastal and ocean sailing, the technology on LNG-powered vessels is relatively mature, but that of ammonia- or hydrogen-powered ships has not matured.

The technology on LNG-powered vessels is relatively mature. LNG is sulfur free, and emits 20% less carbon than traditional fuel. IMO's 0.5% global sulfur cap on marine fuel may push the marine transportation industry to use LNG.

The use of ammonia and hydrogen as clean energy still needs further advancements in technology. Ammonia has been widely used to produce fertilizer, but its use as clean energy has not matured. For example, the use of ammonia relies on engine renovation and a specific energy supply system. The applications of hydrogen energy, to a large extent, require solutions to a number of issues on hydrogen size, density and engines.

In addition, other new energy sources such as methanol may also be used to replace traditional marine fuel.

8.3.5.4 Option 2: Improving Energy Efficiency for Vessels

For energy efficiency, new vessels need to meet requirements from EEDI (Energy Efficiency Design Index), while existing carriers need to comply with SEEMP (Ship Energy Efficiency Management Plan). CE Delf and UMAS estimate that improvement in energy efficiency can help vessels reduce carbon dioxide emissions by up to 8%.

8.3.6 Railway Transport: Zero Carbon Emissions in 2060 Via Electrification-Based Decarbonization

8.3.6.1 Carbon Emissions from Railway Transportation Contracted in the Past Decade Thanks to Higher Electrification Rate

Railway transportation is estimated to have emitted 13.84mn tonnes of carbon in 2019, plunging 50% from 2009 and implying a CAGR of –7.2% in the past decade. Electrification rate in the railway sector expanded 36ppt in the last 10 years, which is a major driver for the plunge in emissions.

8.3.6.2 The Railway Transport Sector Relies on Electrification to Achieve Decarbonization

China's railway operating length totaled 140,000km as of 2019, with 40,000km of railways have not been electrified. The country built about 5,500km of rail lines per annum in the past decade, and these lines are mostly electrified. In addition, an extra 1,050km of old lines went under electrification transformation per year in the last decade. Under a neutral assumption that an extra 1,000km of existing lines become electrified each year in the future, the electrification rate will rise to 100% in 2060. In other words, the railway transport sector may achieve zero carbon emissions in 2060. The cost of railway electrification renovation is Rmb4–6mn/km, indicating renovating 1,000km of railway per year would cost around Rmb4–6bn, accounting for only 4–6% of China State Railway Group's funds available for use. China's railway sector is very likely to achieve full electrification.

Overall, a full range of options that China has on the road to green transportation has been provided. The most important option is the use of new energy. The use of electrical energy (automotive batteries) and hydrogen energy (fuel cells) is essential to emissions reduction in the road and air transportation sectors. The technological roadmaps based on these two options will be discussed in the next section.

8.4 Forecasts for the Use of LIB and Hydrogen Fuel Cell Technologies

As mentioned above, electricity, hydrogen and other new energy sources are crucial to China's initiative of hitting peak carbon emissions by 2030. In the section discussing "green premium", we mentioned that policies and technologies are two major factors that can propel carbon emissions reduction. This section will focus on technologies, especially lithium-ion battery (LIB) technologies and hydrogen fuel cell technologies.

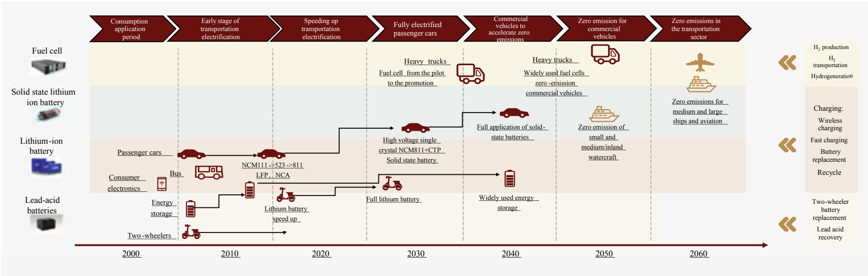


Fig. 8.7 Technologies used in the transportation industry. *Source* GGII, CICC Research

LIB: As an energy carrier for electric vehicles, LIBs are being used widely across the world. Electric PVs with a driving range of 600–800km will achieve price parity over 2021–2025, thanks to lower costs and better quality enabled by advanced battery technologies. New-generation technologies (such as solid-state batteries) are expected to emerge over 2025–2030. The industrialization of these technologies will promote electrification in a growing number of areas such as ships and small aircraft over 2030–2040. Coupled with carbon footprint monitoring in manufacturing and recycling industries, this trend indicates that the industries that utilize LIB are likely to achieve zero-carbon emissions.

Hydrogen fuel cells: Medium- and long-term clean energy solutions to emissions from HDT-based transportation. Due to the characteristics of its cost, the fuel cell system is more likely than LIBs to be used for medium- and long-haul transportation by HDTs. The cost and performance of the hydrogen fuel cell system will meet the commercialization requirements over 2030–2040, and that alternative fuel-enabled electricity generation projects will propel the use and price parity of hydrogen energy. HDT-based transportation will achieve zero-carbon emissions over 2040–2060, given potential commercialization of hydrogen fuel cell systems and hydrogen fuel cell-powered HDTs amid price parity.

The application trend of technologies used in the transportation industry is shown in Fig. 8.7.

8.4.1 LIB to Promote Electrification in PV-Based Transport and Certain Public Transportation Sectors

As mentioned earlier, zero carbon emissions in the PV-based transport sector relies on the eventual adoption of pure electric vehicles. Penetration rate of NEVs (based on sales volume) is likely to reach 100% in 2045, which to a large extent depends on the performance and technological roadmap of LIB technologies.

On the demand side, the incremental installation of electric vehicle (EV) batteries in PVs will peak in China in 2045. Installations will increase at a CAGR of 21% over 2020–2045 and reach 4,140GWh in 2045 (vs. 36GWh in 2020).

There is high visibility regarding the evolution of EV battery technologies and the resulting price parity. In our view, lithium iron phosphate (LFP) batteries will first help NEVs with low- or mid-driving range to achieve price parity with traditional fuel vehicles, and then nickel-rich ternary batteries will follow suit, boosting the market demand. We foresee the commercialization of solid electrolyte batteries, lithium-sulfur batteries, lithium-air batteries, and other next-generation batteries over 2030–2060. We think these trends will further improve the performance of LIB, and enable electrification in additional industries.

Price parity to be partially achieved in the short term (2021–2023): NEVs with selling prices at Rmb100,000–150,000/unit and a driving range of less than 450km will achieve price parity over 2021–2022, thanks to the use of LFP batteries.

Price parity to accelerate electrification in the medium term (2023–2030): As LIB technologies advance and industrialization capability improves, the use of nickel-rich cathode LIBs will accelerate, further reducing their cost and raising their quality. We expect EVs with a driving range of around 600km and more than 800km to reach price parity with fossil-fuel vehicles over 2024–2025 and 2026–2030.

Next-generation technologies to be used in the long term (after 2030): We believe commercialization of next-generation batteries (such as solid-state batteries, lithium-sulphury batteries, and lithium-air batteries) will propel the evolution of advanced battery technologies. These technologies will improve battery safety and enhance battery energy density, thereby increasing the use of NEVs that are more advanced and have a range of more than 1,000km. They will also likely be used in other areas such as small aircraft.

8.4.2 Hydrogen Fuel Cells to Enable Zero-Carbon Emissions from HDT-Based Transportation

Fuel cells are a chemical device that converts the chemical energy contained in fuel into electric energy. According to fuel types, they can be categorized into hydrogen fuel cells as well as methane, methyl alcohol, and ethanol fuel cells. Hydrogen fuel cells are more likely to be commercialized, thanks to multiple advantages (such as safety and clean by-products). Hydrogen energy's volumetric energy density is on par with that of LIB, but it outperforms LIB in terms of mass energy density. As such, hydrogen energy is more likely to be used in long-haul HDTs.

The system cost of hydrogen fuel cells and the cost of using hydrogen energy are both high at the moment. In 2019, the system cost of fuel cells averaged Rmb20,000/kW in China. We estimate that fuel cell systems will reach price parity with HDT engines after the system cost drops to Rmb300–500/kW.

China is also likely to build a domestic value chain in 2020–2025. The country's hydrogen fuel cell industry now relies heavily on overseas materials. Given government subsidies and domestic demand, we believe China can produce its core materials by 2025. The system cost of hydrogen fuel cells is estimated to drop 90% from Rmb20,000/kW in 2019 to Rmb2,000/kW in 2025, thanks to domestic production and the use of advanced technologies from other countries.

Fuel cell system will achieve price parity over 2025–2040 amid further expansion of domestic value chain, major materials advancement and economies of scale. Domestic value chain will expand further and comprehensive system technologies are likely to improve by 2035, thereby helping reduce the system cost to Rmb300–500/kW (down around 70%–80% from 2025). The fuel cell system will reach price parity with traditional HDT engines by 2035.

The costs of manufacturing, transporting, and refilling hydrogen accounts for 25%, 19% and 56% of the total cost of hydrogen consumption in the end market. We expect hydrogen energy to reach price parity driven by diesel with cost reduction in the aforementioned areas.

The two main methods for generating hydrogen include the natural gas and coal gas reforming method and the alternative fuel-based electricity generation method. However, a growing number of companies are trying to generate hydrogen via the alternative fuel-based water electrolysis method in the medium and long term. The cost of hydrogen generation via the reforming method and carbon capture technologies has fallen short of Rmb20/kg in energy-rich regions.

In contrast, amid the current electricity prices, the cost of hydrogen generation via the water electrolysis method is high at more than Rmb40/kg. However, the cost of such hydrogen will drop to less than 10/kg after 2025, as: (1) alternative fuel-based electricity generation accounts for a rising proportion of total electricity generation; and (2) alternative fuel-based electricity prices will likely be low at Rmb0.1–0.3/kWh in energy-rich regions. The cost of such hydrogen will likely drop to around Rmb5/kg after 2040. In addition, economies of scale will produce notable impacts on costs. As such, centralized and large-scale hydrogen generation will play a major role in cost reduction in the medium and long term.

The decline in transport cost depends on technological advances and expansion of application scale. High-pressure hydrogen is mostly transported in Type-III cylinders in China, while it is mostly transported in Type-IV cylinders overseas.[11] The transport cost in 2030 will drop 30%–50% from current levels, thanks to advanced technologies and expansion of application scale in China.

Hydrogen refilling costs are expected to drop markedly with domestic production of key equipment and accelerating construction of hydrogen stations. The cost of building a 35Mpa hydrogen station is high at US$2–2.5mn in China, as: (1) key equipment is being mostly imported from other countries; and (2) depreciation and maintenance account for a high proportion of total hydrogen station cost. The cost of refilling hydrogen will drop rapidly driven by accelerating construction of hydrogen

[11] Type-IV cylinders can contain more hydrogen than Type-III cylinders, and the manufacturing techniques for Type-IV cylinders are more complex.

stations and domestic production of key equipment hydrogen refilling cost will fall short of Rmb10/kg after 2030 (vs. nearly Rmb40/kg at present).

8.5 Supportive Policies to Help the Transportation Sector Achieve Carbon Neutrality

In the previous two sections, we elaborate on the feasibility and ways to achieve carbon neutrality in the transportation industry. In this section, we discuss how to leverage supportive policies to reduce carbon emissions from transportation, and give our policy suggestions from the perspective of industrial development and technological advances.

8.5.1 Policy Suggestions on Industrial Development—PV and CV: Shifting the Focus of Policies Towards Market Orientation and Innovation

8.5.1.1 Domestic Policies on NEVs: Marginal Effect from Subsidies Weakening; "Dual Credit" Policy to Guide Long-Term Industry Development

China's government and governments around the world mainly promote the development of the NEV industry through short-term subsidies and long-term guidance. As subsidies are gradually scrapped in China, the marginal effect from subsidies will weaken, and the "dual credit" policy, as a substitute for subsidy policy, will guide the long-term industry development, in our view. In the EU, automakers that fail to meet the carbon emissions target may face substantial fines, pushing them to shift away from fossil-fuel vehicles to NEVs. In the long term, carbon emission assessment will guarantee the healthy development of the industry following the subsidy cut.

8.5.1.2 Guiding Technological Roadmap to Enhance Overall Quality of NEVs

With subsidies gradually being scrapped, high-quality NEV models will become more important in boosting NEV penetration rate. Therefore, the policy focus should be encouraging automakers to produce more high-quality NEV models.

Guiding technological roadmap: The "dual credit" policy promotes the use of hybrid power technology in fossil fuel vehicles, and requires automakers to further raise the proportion of all-electric vehicles. To accumulate credits, certain vehicle manufacturers produce low-quality NEVs, and sell them to taxi companies at a low price which weighs on NEV demand from individuals. We believe the criteria for granting credits can be further specified. For example, indicators such as driving range, battery safety, and energy conversion efficiency could be considered to encourage the production of higher-quality NEVs.

Vehicle-related taxation: Allowing local governments to collect part of the vehicle-related tax revenue can stimulate cooperation between local governments and local automakers. Taxation policies should encourage both purchases and the use of NEVs.

8.5.1.3 Encouraging Innovation to Remove Hindrances to NEV Sector Development

LIB technology is not yet mature. Policies should be directed at removing customer pain points in NEV purchases and promoting the development of NEV infrastructure.

The focus of subsidies should gradually shift from NEV purchases to the development of NEV infrastructure. In particular, subsidies are necessary to fund the construction of infrastructure facilities such as EV charging spots and EV battery swapping stations, so as to enhance the convenience of driving NEVs.

Policymakers should support business model innovation. For example, selling NEVs and batteries separately can reduce the initial vehicle purchasing cost, and quell consumer concerns on battery life. However, China needs to launch new policies to clearly define the ownership of NEVs and batteries. In addition, EV battery swapping stations are mainly operated under an asset-heavy model, and require heavy investment in the early stages. These stations are unlikely to achieve large-scale commercialization unless they receive government subsidies and capital market support.

8.5.1.4 Reduction of Carbon Emissions from Vehicles on the Road

Forming more environmentally friendly driving habits: Improper driving behavior such as street racing and poor driving habits such as random lane changes cause extra gasoline consumption as well as additional carbon emissions. Therefore, applying driver-monitoring technology will better discipline drivers, and further reduce carbon emissions from vehicles.

Internet-connected vehicles to reduce traffic jams: Vehicles that are connected to the internet can choose the best route based on cloud data, enhancing transportation efficiency. Thus, the installation of roadside sensors and signal reception devices will effectively promote internet-connected vehicles, thereby reducing carbon emissions.

8.5.2 Policy Suggestions on Industry Development—Airlines: Focusing on Development of Biomass and Hydrogen Energy

8.5.2.1 Alternative Energy Sources: Offering Subsidies for Mature Biomass Fuels; Paying Attention to the Development of Hydrogen Energy

We believe the government can offer subsides to create the aviation biomass fuel market. Biomass fuels for aircraft are expensive, which is a major restraint on market demand and economies of scale. We thus believe regulators should offer subsidies to fill the price gap between biomass fuels and traditional fuels to promote the development of the biomass-fuel value chain.

We believe the government should promote the combination of other new energy sources such as hydrogen with aeroengines. China still lags other countries in aircraft manufacturing technology, and we suggest paying attention to hydrogen-enabled technological advances.

8.5.3 Policy Suggestions on Technological Advances—LIB: Zero Emissions Throughout the Lifecycle Requires Coordination Between Companies and Governments

Carbon emissions from LIBs should be evaluated throughout the full lifecycle. While driving cars powered by LIBs is carbon emission-free, the manufacture of LIBs and treatment of used LIBs both produce carbon emissions.

China needs to further improve policies to push the automotive battery value chain to achieve zero carbon emissions. A number of authorities have released a series of policy moves to strengthen recycling of unused NEV batteries. However, they have not clarified the details. In addition, China also needs to issue clear policies to push NEV producers to save energy and reduce carbon emissions. We suggest policymakers take the following actions:

Establishing a system of traceability management during the battery lifecycle to track carbon footprints in each step: The Ministry of Industry and Information Technology (MIIT) has built a comprehensive management platform for national NEV monitoring and automotive battery recycling. Authorities also need to promote carbon footprint traceability in each step of the value chain, and ensure effective implementation of a system that incorporates rewards and punishments, in order to push the value chain to control and reduce carbon emissions.

Clarifying the parties liable for automotive battery recycling, and building a recycling network that consists of 4S stores, NEV producers and third-party institutions: The Ministry of Industry and Information Technology (MIIT) has clearly stated that NEV producers are held liable for recycling automotive batteries. Thus, China needs to further improve the recycling network, clarify the details on storage, logistics and reprocessing, and explore viable business models and interest-distribution options.

Relying on mandatory policies and a system that incorporates both carrots and sticks to guide alternative fuel vehicle makers and users to actively participate in automotive battery recycling: China has built a system of LIB traceability and recycling, but compliant channels have not played an important role in the recycling. The government should set up a clear system that incorporates rewards and punishments, clarify regulatory options, and make NEV makers more interested in recycling. In addition, China also needs to strengthen the automotive battery traceability system, and rely on rewards or subsidies to guide users to participate in recycling.

8.5.4 Policy Recommendations—Fuel Cells: It is Necessary to Promote Industrialized Applications of Fuel Cells Via Policies

The adoption of hydrogen fuel cells is still at a very early stage. Chinese suppliers of hydrogen fuel cells lag their foreign counterparts in terms of both expertise and scale. In addition, the adoption of hydrogen fuel cells requires substantial infrastructure investment, and the hydrogen fuel cell industry cannot offer decent returns in a long time if there are no supportive policies. In other words, R&D, production, adoption, and infrastructure construction all need policy support.

Current policies: China launched a 4-year campaign of pilot promotions of hydrogen fuel cell-powered vehicles in September 2020. In the period of the pilot promotions, the country aims to build a full value chain, focus on technological innovations, target applications in actual scenarios and explore effective business models to support healthy development.

Our longer-term policy recommendations: Given FCH-JU's report *Hydrogen Roadmap Europe: A sustainable pathway for the European Energy Transition*, the adoption of hydrogen fuel cells needs the following supportive policies in the long term:

First, policymakers should promote construction of hydrogen energy infrastructure and formulation of fuel cell standards, and clarify liabilities of each party in the value chain. The hydrogen fuel cell industry now lacks regulatory standards, especially on the infrastructure side. Formulating standards can facilitate construction and investment of hydrogen fueling stations, and accelerate infrastructure construction. In addition, the hydrogen fuel cell system also needs to further improve technological, production and qualification standards to promote mass adoption.

Second, China needs to formulate a long-term infrastructure construction plan to ensure large-scale adoption and visible development in the medium and long term.

The country also needs to further clarify and guide adoption roadmaps for hydrogen energy in specific transport scenarios, and make clear promotion targets.

China should promote cross-border cooperation on the adoption of hydrogen fuel cell systems, expand its coverage of the global value chain, and accelerate industrial expansion.

8.6 Reassessing the Effectiveness of Our Green Transportation Solutions Based on the "Green Premium"

In previous sections, we predicted the trend of carbon emissions from transportation by 2060, and discussed green transportation solutions including technological roadmaps and necessary policies. In this section, we measure the effects of these solutions again from the perspective of "green premium".

8.6.1 The "Green Premium" to Decline Considerably, but Unlikely to Plunge to Zero in 2060

As estimated in the previous section, the "green premium" for the transportation industry is 68% in 2021, implying a zero carbon-emissions cost of Rmb2.7trn. This indicates decarbonization in this industry would be costly and challenging. Given our forecast carbon-emissions trends, we intend to calculate the "green premium" in 2030 (when emissions may peak) and in 2060. Then we try to answer two questions: (1) What will be the cost of zero carbon emissions in 2030 and 2060? (2) How will the "green premium" change from the current level? Answers to these questions can measure the effectiveness and feasibility of our recommended technological roadmaps and policies.

8.6.1.1 Zero Carbon Emissions Cost to be Rmb89.7bn in 2030, Implying a "Green Premium" of 2%

The estimation that the "green premium" in the transportation industry should be 2% in 2030 implies zero carbon emissions cost of Rmb89.7bn (Table 8.4), down about Rmb2.6trn from 2021 with around Rmb1.7trn (or 65%) from the CV-based transport sector and about Rmb750bn (or about 29%) from the PV-based transport sector.

The CV-based transport sector's zero carbon emissions cost is expected to decline Rmb1.7trn to Rmb242.3bn in 2030. Specifically, we estimate that the zero emissions cost of the HDT transport submarket will drop by Rmb1.5trn due to a combination of falling hydrogen cost (–52%) and lower purchase price of hydrogen-powered HDTs (–80%). We expect the zero emissions cost of the MDT and LDT transport submarkets to slide about Rmb180bn. In our view, the purchase price of electric

Table 8.4 We expect the transportation industry's zero carbon emissions cost to be Rmb89.7bn in 2030

2030E	Current energy cost (Rmb bn)	Cost after new energy (Rmb bn)	Cost of zero carbon emission (Rmb bn)	Green premium (%)
Road transport (freight)	1,847	2,089	242	13
Road transport (passenger)	3,493	3,159	–333	–10
Railway	45	35	–10	–22
Aviation	136	287	151	111
Shipping	37	77	40	107
Total	5,557	5,647	90	2

Source CICC Research

MDTs and LDTs will decline 38%, pushing down their lifecycle cost. We estimate that per-unit cost of electric MDTs and LDTs in 2030 would be 17% lower than the cost of those using traditional fuels (vs. a 7% premium in 2021).

The PV-based transport sector's zero carbon emissions cost will shrink about Rmb750bn to –Rmb333.5bn in 2030 with purchase price parity of pure electric PVs. As mentioned previously, we expect pure electric PVs to achieve purchase price parity with traditional fuel PVs in 2025 and per-unit electricity cost to be 60% lower than gasoline cost. The full lifecycle cost of pure electric PVs in 2030 (Rmb0.47/km) will be 10% lower than that of traditional fuel PVs (Rmb0.53/km). And this sector's zero emissions cost will be around –Rmb333.5bn.

8.6.1.2 The "Green Premium" to Be 2% in 2060, but Zero Carbon Emissions Cost to Drop to Rmb70.1bn

The "green premium" in the transportation industry will be 2% in 2060, implying zero carbon emissions cost of Rmb70.1bn (Table 8.5). The "green premium" in the PV-, CV- and railway-based transport sectors are expected to be all zero in 2060 due to full penetration of new energy. In contrast, the aviation and marine transportation sectors' zero carbon emissions cost will be Rmb53.7bn and Rmb16.4bn in 2060, implying a "green premium" of 18% and 31%, as their energy demand cannot be fully met by new energy and per-unit hydrogen consumption cost should remain higher than fuel cost in 2060. Overall, the transportation industry's zero carbon emissions cost should be Rmb70.1bn in 2060, implying a "green premium" of 2%.

Generally speaking, we think the "green premium" in the transportation industry will plunge from 68% in 2021 to 2% in 2060, with the implied zero carbon emissions cost slipping from Rmb2.7trn in 2021 to Rmb89.7bn in 2030 and Rmb70.1bn in 2060. This indicates our recommended solutions are reasonable. Nevertheless, the "green premium" is unlikely to drop to zero in 2060, suggesting the transportation industry

Table 8.5 We expect the transportation industry's zero carbon emissions cost to be Rmb70.1bn in 2060

2060E	Current energy cost (Rmb bn)	Cost after new energy (Rmb bn)	Cost of zero carbon emission (Rmb bn)	Green premium (%)
Road transport (freight)	1,530	1,530	–	0
Road transport (passenger)	2,494	2,494	–	0
Railway	55	55	–	0
Aviation	298	352	53.7	18
Shipping	52	69	16.4	31
Total	4,429	4,499	70.1	2

Source CICC Research

still requires more advanced technologies. The decline in the "green premium", to a large extent, relies on advances in LIB and hydrogen technologies. LIB technological roadmap remains visible, while development of hydrogen technology is uncertain and requires policy support for R&D, adoption and criteria formulation.

8.7 Outlook for Green Transportation: A Combination of Autonomous Vehicles, Super High-Speed Trains and Supersonic Aircraft

We discussed the future based on visibility on technological development in previous sections. This section will picture the future of the transportation industry in 2060 that is 4 decades away from now. In the future predicted by us, modes of transportation in 2060 are very likely to include autonomous vehicles, hyperloop trains (super high-speed trains) and supersonic aircraft.

8.7.1 Autonomous Driving: It Changes More Than Travel

Autonomous driving requires highly effective coordination among vehicles, persons and the environment, and can complement normal driving under complicated conditions.

8.7.1.1 Autonomous Driving to Change Travel Habits and Significantly Improve Road Transport Efficiency

The impact of complete autonomous driving on road transportation includes the following:

In the era of autonomous driving, vehicles will become the “third space” between home and office. Internal space in vehicles will be designed based on user needs to meet the comfort requirements from passengers. What’s more, vehicles will become the “third space” instead of a means for travel, and passengers can work, relax and play inside vehicles.

Part of the travel demand will be diverted away from air and railway transportation to autonomous vehicles. For example, users in Beijing may sleep in an autonomous vehicle and arrive in Shanghai the next day.

Autonomous driving can effectively raise a vehicle’s utilization rate and enhance transport efficiency. In our view, autonomous driving will promote PV sharing and raise utilization rate, and can help resolve safety problems such as driver fatigue and further enhance transport efficiency.

8.7.1.2 Rising Penetration of Autonomous Driving to Produce a Profound Impact on Infrastructure Construction

Autonomous driving will reshape the concept of road and promote the construction of multi-tiered underground tunnels. The era of autonomous driving will trigger large-scale construction of these tunnels. Autonomous vehicles can drive in tunnels with different depths, significantly enhancing road transport efficiency.

The demand for new parking lots will decline, saving urban land resources. Since autonomous driving will trigger the sharing economy in the area of travel, idle vehicles will no longer occupy parking space, and urban demand for parking lot construction will shrink considerably, thereby saving urban land resources.

8.7.2 Can Hyperloop Trains be Realized?

Hyperloop train is a mode of transport that Elon Musk proposed and is based on the theory of evacuated tube transportation. They have a number of advantages, such as high speed, low energy consumption, quietness and low pollution. The US and China have both made a big step in the R&D of hyperloop trains. For example, Virgin Hyperloop in the US completed its first test ride with passengers in November 2020. China’s Southwest Jiaotong University experimented with a hyperloop train with an hourly speed of more than 600km in January 2021.[12]

[12] https://www.163.com/dy/article/G0831MQ20511NEUN.html (source in Chinese).

If hyperloop trains are commercialized, they will reshape existing transportation systems and lifestyles.

Hyperloop trains have a faster theoretical speed than aircraft, and are very likely to affect the role of airplanes in long-distance travel. As a carbon-free mode of transport, hyperloop trains can help the transportation industry achieve carbon neutrality after replacing aircraft.

Moreover, we believe the development of hyperloop trains is very likely to redefine the concept of cities. For example, passengers in Shanghai might arrive in Beijing or Shenzhen in only 1 hour if they travel by hyperloop train. In other words, Beijing, Shanghai and Shenzhen would be as close to three places in a city.

The speed of hyperloop trains is amazing, and we believe supersonic aircraft with faster speeds are likely to be commercialized in the years ahead.

8.7.3 Commercialization of Supersonic Aircraft Likely to Be in Sight

Supersonic aircraft can travel at about 1,200km per hour, which is faster than the speed of sound. Passenger and cargo aircraft have been subsonic for around 100 years since their inception. Yet fundamental changes are likely to take place in the coming years. Boom Supersonic released XB-1,[13] the first supersonic demonstrator, in October 2020. According to its announcement, the test flight is set to take place in 2021, with the highest speed at 2,335km per h. The XB-1 can carry only two people, and is still only a demonstrator. The real bright spot is Boom Supersonic's Overture that can transport 55–75 people. Boom Supersonic expects Overture to be commercialized in 2025.

Energy consumption by supersonic aircraft is more than double that of existing airplanes. Will they increase carbon emissions from the air transportation sector? Our analysis shows that they will not necessarily increase the emissions. XB-1's design, development and tests have all taken environmental impact into consideration. For example, when XB-1 is tested on the ground, 80% of the fuel consumed is clean fuel. If clean fuel applications in supersonic aircraft prove viable, this will significantly reduce carbon emissions. Supersonic aircraft can shorten the travel time and may also help the air transportation sector achieve carbon neutrality.

[13] https://boomsupersonic.com/xb-1

Chapter 9
Living Green: New Chapter of Consumption and Social Governance

Abstract We all hope that everyone can protect the earth and live a better life. As consumers are the last link in the carbon emission chain, hundreds of millions of consumers need to play their part in achieving the carbon peak by 2030 and carbon neutrality by 2060. Everyone can contribute by changing the way they live and consume.

In the meantime, consumers may face increased costs and inconvenience brought by green consumption. However, we believe this is a worthwhile since changes and sacrifices of several generations will bring a better life for future generations.

In this chapter, we emphasize the need to change our lifestyle and social governance as well as the reinforcing interaction between the two. Enterprises should take measures to effectively lower cost and improve economies of scale, quality and experience of green consumption. Governments should improve green standards, introduce subsidies and formulate policies and regulations to facilitate consumers' shift to green consumption and lifestyle changes.

Let us work together to build healthies lifestyles with clear water and green mountains, and to build and share a beautiful era of carbon neutrality.

9.1 Living Green Needs Efforts of All Stakeholders

9.1.1 Low-Carbon Lifestyle is of Great Significance as Households Are Responsible for 40% of Total Carbon Emissions

Households generate carbon emissions both directly and indirectly. Energy consumption contributes directly to the carbon footprint of households, while indirect carbon emissions are generated by consumption and services purchased in daily life. According to the definition of 'carbon footprint', indirect carbon emissions also include emissions generated in producing consumer goods. We estimate that carbon

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_9

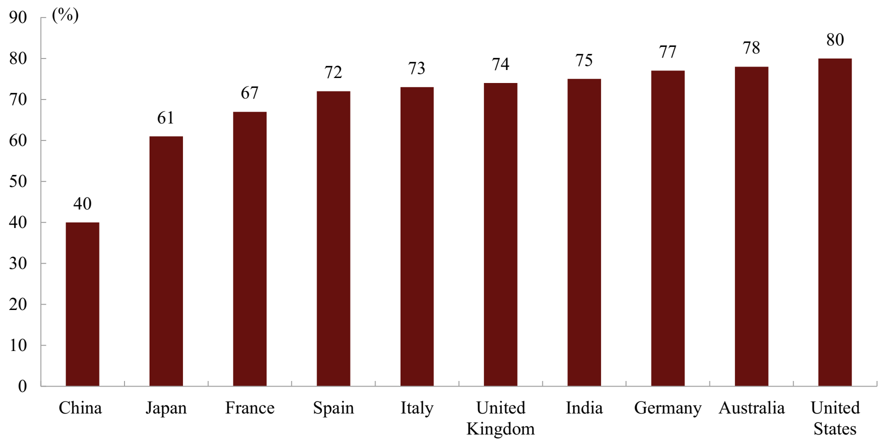


Fig. 9.1 Proportions of household carbon footprints by country. *Note* Research data is compiled based on 2017 data. *Source* Mapping the Carbon Footprint of EU regions, Diana Ivanova et al. Environ. Res. Lett. 12 (2017) 054013, How to Reduce Household Carbon Emissions: A Review of Experience and Policy Design Consideration, Xiaoling Zhang et al. Energy Policy 102 (2017) 116–124, CICC Research

emissions from households account for approximately 40% of China's total emissions,[1] compared to 60%–80% in developed economies[2] (Fig. 9.1). Households may account for a higher proportion of total carbon emissions as their living standards improve. Therefore, living a green lifestyle is crucial for carbon neutrality.

9.1.2 Social Governance Requires Efforts from Households, Companies, and Government

How to lower the proportion of household carbon footprint in total carbon emissions? A low-carbon lifestyle may play an important role in achieving carbon neutrality. As the economy continues to grow, the proportion of household carbon footprint is increasing. Living a low-carbon lifestyle has become increasingly important, and needs the engagement of all stakeholders: Households should turn to low-carbon consumption, businesses should step up innovations and efforts to reduce supply-side carbon emissions, and governments should introduce favorable policies. Therefore, breakthroughs relating to household lifestyles, business models, and government policies are necessary to achieve green consumption (Fig. 9.2).

What can households do to help achieve carbon peak? Households can take measures to reduce demand-side carbon emissions, such as adoption of green

---

[1] How to Reduce Household Carbon Emissions: A Review of Experience and Policy Design Consideration, Xiaoling Zhang et al. Energy Policy 102 (2017) 116–124.

[2] Mapping the Carbon Footprint of EU Regions, Ivanova et al. Environ. Res. Lett. 12 (2017) 054,013.

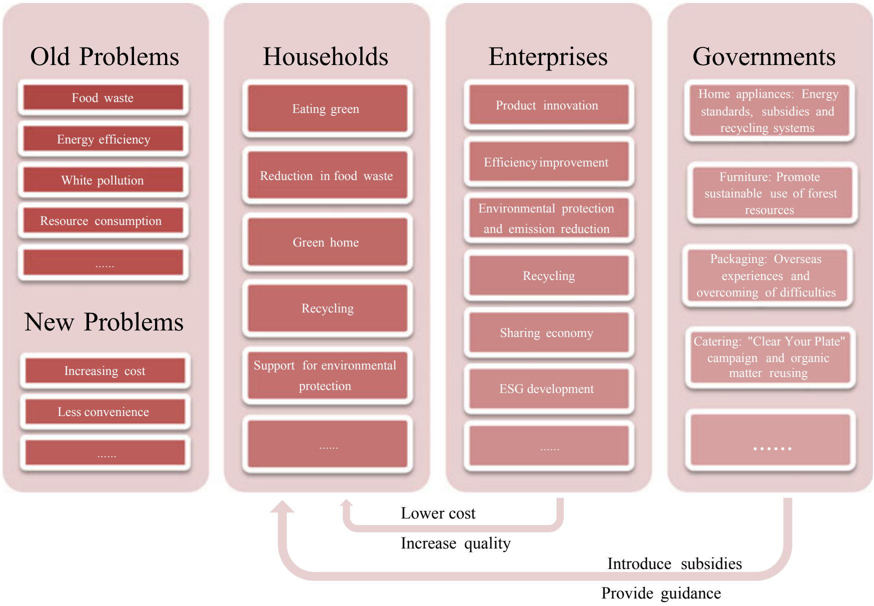


Fig. 9.2 Roadmap of green lifestyle. *Source* CICC Research

lifestyles, cultivation of green consumption habits, improvement of consumer behaviors, as well as practicing a low-carbon diet, waste reduction, energy conservation and environmental protection.

However, households may face new problems in this process, i.e., rising costs and inconvenience. The engagement of enterprises and governments can help address these issues and enable households to play their roles in the achievement of carbon neutrality.

What can consumer goods companies do to help achieve carbon peak? Enterprises can take multiple measures to reduce supply-side carbon emissions, such as product innovation, efficiency improvement, energy consumption reduction, environmental protection, recycling, reusing, sharing economy, and ESG development. In addition, enterprises can achieve economies of scale in green consumer products to lower household expenses on their products.

What can governments do to help achieve carbon peak? Governments should introduce favorable policies to encourage enterprises to take more ambitious measures. These policies include energy efficiency system and recycling of home appliances, subsidies for energy-saving products, sustainable use of forest resources, comprehensive management of packaging, “Clear Your Plate” campaign and reusing of organic products. Implementation and improvement of these policies may also help lower the incremental cost of households.

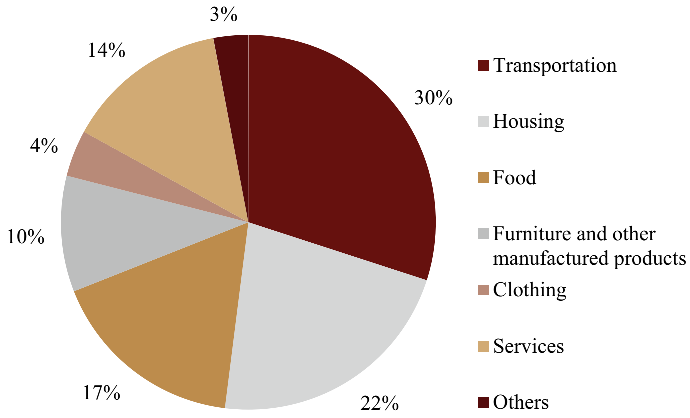


Fig. 9.3 Carbon emission breakdown of European households in 2017. *Source* Mapping the Carbon Footprint of EU Regions, Diana Ivanova et al. Environ. Res. Lett. 12 (2017) 054,013, CICC Research

9.2 Green Lifestyle: What Can Households Do to Help Achieve Carbon Peak?

Studies have shown that transportation, food, housing, furniture and other manufactured products account for 30%, 17%, 22%, 10% and 4% of the average carbon footprint of European households in 2017 (Fig. 9.3) (see Footnote 2). This section mainly discusses green diet and green home that jointly account for approximately 39% of the average household carbon footprint.

9.2.1 Eating Green

Vegetarian diets produce much lower carbon emissions than meat, mainly due to low utilization of feed and methane gas emissions from animals. Carbon emissions generated by producing beef and mutton are four times as high as those from chicken and pork[3] (Fig. 9.4). On the average US diet, meat products account for 56.6% of total carbon emissions in 2018, being the largest component of dietary carbon emissions[4] (Fig. 9.5). As for dietary consumption is mainly rice, meat products account for approximately 36.6% of all carbon emissions from food in China in 2016 (Fig. 9.6).

[3] A Comparative Study on Carbon Footprints Between Plant and Animal-based Foods in China, Xu et al. Journal of Cleaner Production 112 (2016) 2581–2592.

[4] Center for Sustainable Systems, University of Michigan, 2020.

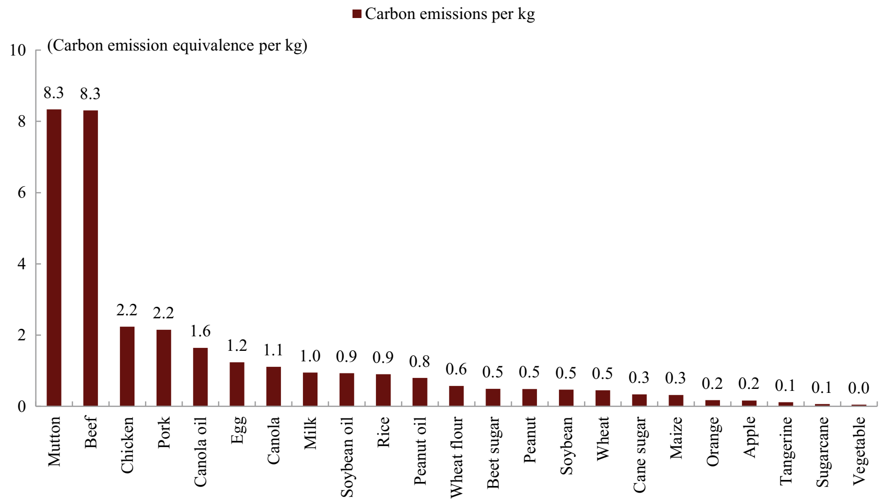


Fig. 9.4 Estimated per kg carbon emission from food production and consumption in China. *Source* A Comparative Study on Carbon Footprints Between Plant and Animal-based Foods in China, Xu et al. Journal of Cleaner Production 112 (2016) 2581–2592, CICC Research

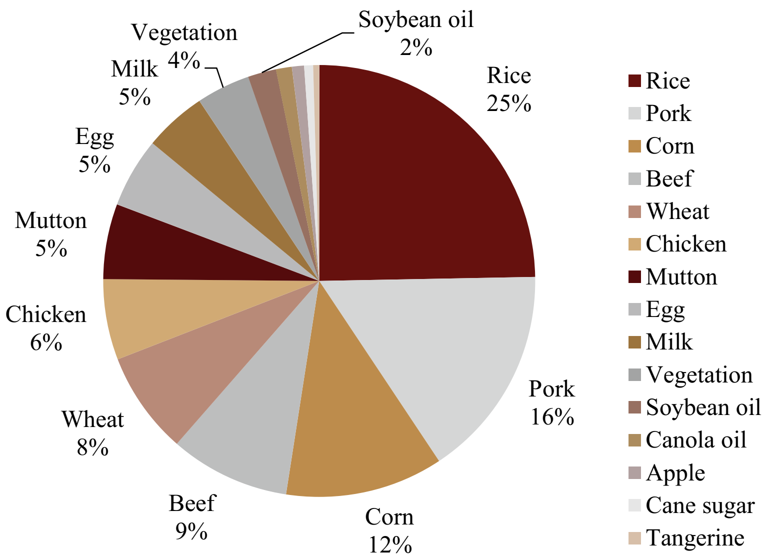


Fig. 9.5 Carbon footprint breakdown by type of food in 2016 in China. *Note* Data on carbon footprint of aquatic products is not available. *Source* Food and Agriculture Organization, A Comparative Study on Carbon Footprints Between Plant and Animal-based Foods in China, Xu et al. Journal of Cleaner Production 112 (2016) 2581–2592, CICC Research

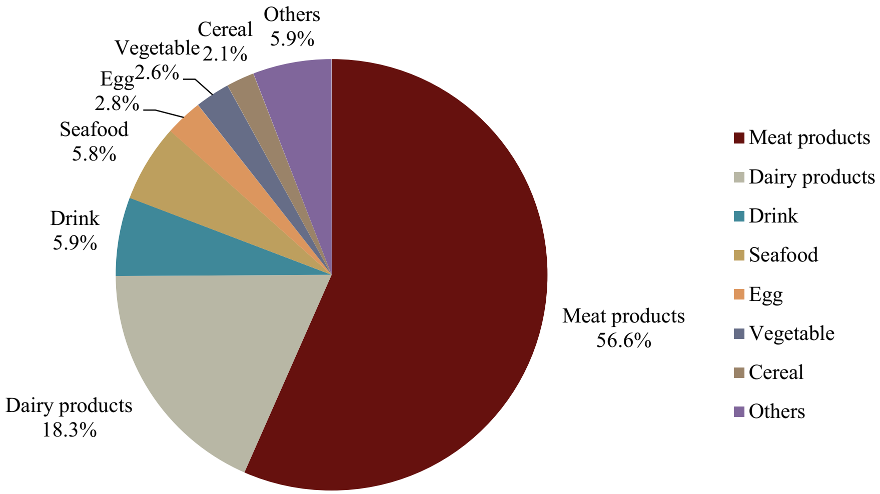


Fig. 9.6 Carbon footprint breakdown by type of food in 2018 in the U.S. *Source* Center for Sustainable Systems, University of Michigan, CICC Research

For adults, carbon footprints of vegan diets and ovo-lacto vegetarian diets are 59% and 65% of that of omnivorous diets,[5] and could provide all the nutrients that a human being needs.[6] According to our calculations, improving eating habits alone can reduce carbon emissions by 66.21mn tonnes by 2030. Therefore, green diet can play an important role in achieving carbon peak by 2030 and carbon neutrality by 2060.

The improvement of the dietary structure depends on government advocacy and guidance, as well as on innovations in food processing. Using vegetarian food to emulate meat can minimize changes in tastes from the adjusted dietary structure, which will help the transformation of dietary structure. Among these innovations, plant-based meat production technology has advanced. Founded in 2009 (US), Beyond Meat has become the world's largest producer of plant-based meats. The company's plant-based products are designed to have the same taste as animal-based meat. Beyond Meat offers Beyond Burger, Beyond Beef, Beyond Fried Chicken, and Beyond Sausage, covering various products. According to 3Q20 earnings announcement, Beyond Meat's market share of the US retail channel increased 6.14 ppt YoY in 3Q20.

Eating more vegetables, moderate amount of poultry and less red meat, as well as switching to an ovo-lacto vegetarian diet may reduce carbon emissions and could be good for health. Compared to veganism, ovo-lacto vegetarianism may be more easily accepted since it provides nutrition within a more flexible dietary framework.

[5] Environmental Impact of Omnivorous, Ovo-lacto-vegetarian, and Vegan diet, Alice Rosi et al. Scientific Reports, 7,6015(2017).

[6] Nutrient Intake of Endurance Runners with Ovo-lacto-vegetarian Diet and Regular Western Diet, M. Eisinger et al., 1994.

Extensive research shows an ovo-lacto vegetarian diet has potential health benefits. According to *The Long-term Health of Vegetarians and Vegans*, the prevalence of overweight and obesity is lower among ovo-lacto vegetarians and vegans. In addition, ovo-lacto vegetarians and vegans have a lower risk of ischemic heart disease (IHD), and longer life expectancy compared with non-vegetarians from a similar background. Studies also show that compared with eaters of other meats, red meat eaters have a much higher risk of a range of diseases.[7] The World Health Organization (WHO) announced that the consumption of red meat is probably carcinogenic to human beings (Group 2A). Therefore, we suggest eating less red meat, moderate poultry meat, and more vegetables, and considering adopting an ovo-lacto vegetarian diet.

9.2.2 Reduction in Food Waste

Food waste at the consumer level is a massive problem, especially at banquets and get-togethers. As consumer spending rises, food waste in China is concentrated at the consumer level. According to the *2018 China Urban Catering Food Waste Report* released by the World Wide Fund for Nature (WWF) and the Institute of Geographic Sciences and Natural Resources Research of the Chinese Academy of Sciences, food waste in China's restaurant industry is 93g/person/meal, implying a waste rate of 11.7%. Food waste in urban restaurants was about 17–18mn tonnes in China in 2015. The Chinese Academy of Social Sciences also points out that China wastes 40–50mn tonnes of grain every year, equivalent to 6.0%–7.5% of the country's annual grain production.

Food waste is more severe for special events such as friends' get-togethers, weddings, birthdays, and business banquets. According to the *2018 China Urban Catering Food Waste Report*, the average food waste is 107g/person/meal and 102g/person/meal at friends' get-togethers and business banquets, compared to 95g/person/meal for family gatherings and 67g/person/meal for a typical dinner. Food waste is positively correlated to restaurant size. Large restaurants have the largest food waste of 132g/person/meal, compared to an industry average of 93g/person/meal, and 69g/person/meal for small restaurants and 38g/person/meal for fast-food restaurants.

Reducing food waste in restaurants can lower carbon emissions from food production and reduce greenhouse gas emissions generated by waste going to landfills. In addition, households should purchase consumer goods, such as household supplies, grocery, and clothing, according to actual needs. These moves can help protect natural resources and achieve carbon peak.

---

[7] The Long-term Health of Vegetarians and Vegans. Paul et al. Proc Nutr Soc. 2016 Aug;75(3):287–93.

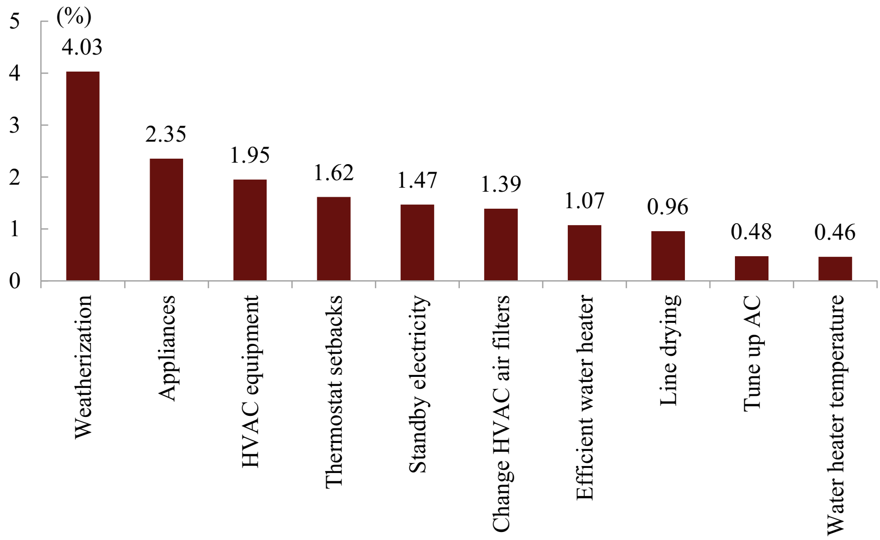


Fig. 9.7 Green home—estimated carbon emission reduction resulting from adoption of certain habits. *Source* Household Actions Can Provide a Behavioral Wedge to Rapidly Reduce US Carbon Emissions. Thomas Dietz et al. PNAS.0908738106, CICC Research

9.2.3 Green Home

Adopting certain habits can help reduce carbon emissions. Although households account for more than 20% of household carbon footprint, there is no simple solution for reducing carbon emissions of home life. Reducing such carbon emissions depends on technological advancements and energy mix improvements, and more importantly, some daily habits. According to the research from Michigan State University, the adoption of a green lifestyle can reduce carbon emissions of home life by more than 15%[8] (Fig. 9.7). Good lifestyles include energy-saving renovation of houses, renovation and maintenance of home appliances, drying clothes under the sun instead of using laundry dryer, and lower temperature of hot water. In addition, waste sorting is also an important part of green home habits.

9.2.4 Support for Environmental Protection

As environmental awareness increases, people's consumption patterns will play a bigger role in helping China achieve carbon neutrality.

[8] Household Actions Can Provide a Behavioral Wedge to Rapidly Reduce US Carbon Emissions. Thomas Dietz et al. PNAS.0908738106.

Reducing food delivery packaging is an important measure to protect the environment. As the food delivery packaging market is rapidly expanding, left over food packaging has become an important issue and needs to be solved urgently. Consumers can play their roles in reducing unnecessary packaging. Specific measures include reuse of packaging, reduced use of disposable products, and wide use of durable products. The food delivery market is booming due to the popularization of mobile internet. According to iResearch, China's food delivery market increased 39.3% YoY to Rmb653.6bn in 2019, implying a CAGR of 90% over 2015–2019. We estimate that, in China, the number of disposable food boxes used in food delivery of restaurants might exceed 30bn in 2019, and the number of packaging bags may exceed 15bn.

Plastics are the main materials for food delivery packaging at current stage. According to Meituan Waimai, the proportion of plastic materials in food delivery packaging boxes and bags exceeds 80% in 2020. Polypropylene and polyethylene are the most widely used plastic materials. The treatment and recycling markets of food delivery packaging waste remain underdeveloped, and plastics generate a large volume of carbon emissions during landfills or incineration. Constraints in technology, performance and cost prevent degradable packaging from being reused widely.

In addition, there are many things we can do to reduce carbon emissions, such as buying e-books and using paper cups less frequently. As environmental awareness increases, we can protect our future by supporting environmental protection.

9.3 Green Business Model: What Can Consumer Goods Companies Do to Help Achieve Carbon Peak?

In the process of reaching carbon peak, enterprises can play an active role in product innovation, efficiency improvement, energy consumption reduction, environmental protection, emission reduction, recycling, economic sharing, and ESG development. These measurements can effectively increase economies of scale, lower cost, and improve the quality and experience of green consumption.

9.3.1 Product Innovation

Product innovation can lead to slower growth in household energy consumption. Chinese households consume large volumes of electricity and natural gas, along with a small amount of bulk coal to meet the needs of home appliance operation, cooking, and heating. In 2019, Chinese households consumed 1025bn kWh of electricity, implying 705mn tonnes of carbon dioxide emissions (China's clean energy accounted for 31% of total electricity generation in 2019); 114bn m^3 of natural gas, implying 246mn tonnes of carbon dioxide emissions; and 60mn tonnes of bulk coal (mainly for heating), implying 114mn tonnes of carbon dioxide emissions.

Electricity demand by residential users is relatively inelastic. To fundamentally solve the carbon emission problem of household electricity consumption, use of renewable energies such as wind, solar, and hydropower needs to increase substantially, while the use of coal-fired thermal power generation should be reduced. Improving energy efficiency standards of home appliances may help reduce the usage of household electricity. Newly produced home appliances, especially air conditioners and central air conditioners, are more energy efficient. Moreover, the older the home appliance is, the lower its average energy efficiency. Trade-in programs should be introduced to substitute home appliances with poor energy efficiency.

Many new technologies can facilitate the improvement of home appliances' energy efficiency. Inverter technology can improve energy efficiency of air conditioners, refrigerators, and washing machines. Solar water heaters and condensing gas water heaters can alleviate the burden on power grid. LED lights could replace the traditional light bulbs.

9.3.2 Efficiency Improvement and Energy Consumption Reduction

Material loss in the process of production is another important factor affecting carbon emissions. The furniture industry is using flexible production and other intelligent manufacturing technologies to continuously improve the utilization rate of timber. In this section, we use the furniture industry as an example to illustrate the potential of the industry's efficiency improvement and energy consumption reduction.

China is the world's second largest consumer of timber, and its timber consumption has continued to increase in recent years (Fig. 9.8). Reducing timber consumption and improving its utilization can play an important role in helping achieve carbon neutrality. The amount of plantation, especially in the form of tree, is crucial for carbon neutrality. One tree can absorb more than 21.8 kg of carbon dioxide per year (Fig. 9.9). According to data from the China National Forest Products Industry Association and Qianzhan Intelligence, China's timber consumption has increased 173% in the past decade and it has become the world's second largest consumer and largest importer of timber. The proportion of home furnishings in total timber consumption continues to increase. Wood-based panels account for the highest proportion, at 32.99%, and solid wood furniture products account for about 3%.

As the major consumer of timber, furniture and home decoration industries continuously improve the utilization rate of wooden products through intelligent manufacturing and flexible production. Currently, the timber utilization rate at some leading manufacturers of custom-made furniture exceeds 85%. This utilization rate can effectively lower timber consumption and help achieve carbon neutrality.

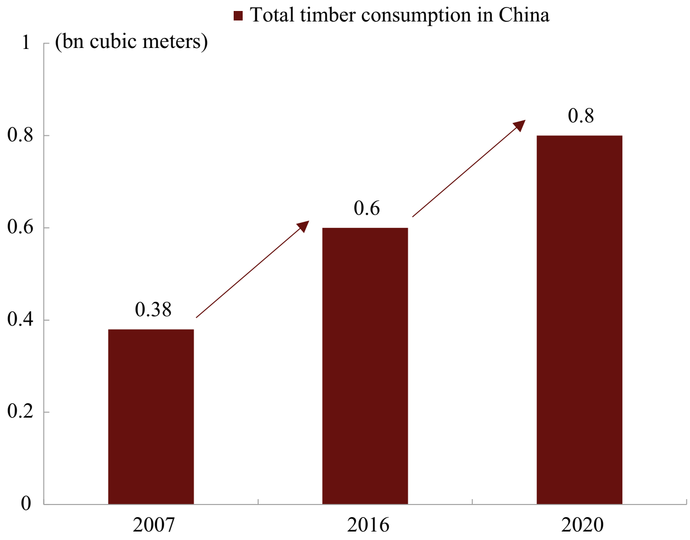


Fig. 9.8 China's timber consumption continues to rise. *Source* China National Forest Products Industry Association, chinatimber.org, CICC Research

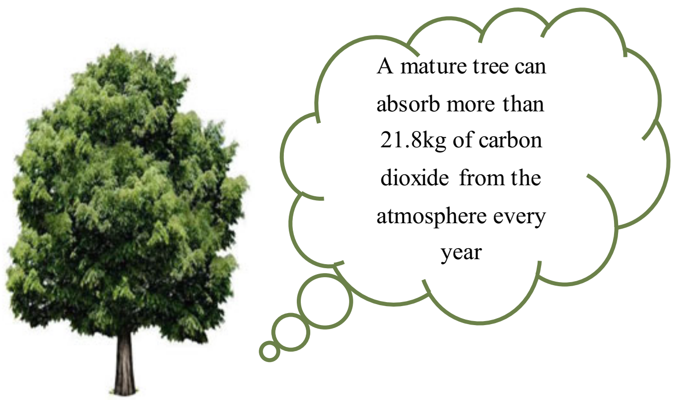


Fig. 9.9 One tree can absorb more than 21.8kg of carbon dioxide per year. *Source* Arbor Day Foundation, CICC Research

Intelligent manufacturing technologies such as advanced flexible production can fully meet the needs of furniture customization. Through the organic combination of microelectronics, computer and system engineering technologies, flexible production technology can effectively cope with the contradiction between high automation and high flexibility in mechanical manufacturing. The technology uses big data and software to automatically combine, calculate, and arrange cabinets of different sizes to design the most efficient sawing process. This can help reduce material losses, improve timber utilization rate, and lower timber consumption. China's leading manufacturers of custom-made furniture such as Oppein and Suofeiya continue to increase their timber utilization rate using flexible production technologies.

9.3.3 Environmental Protection and Emission Reduction

Environmental pollution resulting from the production process is one of the major obstacles to achieving carbon neutrality. We will use the personal care and textile & apparel industries as examples to analyze the relation between pollution emission and carbon neutrality and corresponding solutions.

9.3.3.1 Manufacturers of Laundry Detergent Have Stepped up Efforts to Reduce Carbon Emissions

Reduction of carbon emissions in the process of producing laundry detergent plays an important role in achieving carbon neutrality. China's laundry detergent consumption is huge. In 2019, China's laundry detergent market size reached Rmb27.2bn. Assuming an average price of Rmb7.8/500g, China consumed 1.744mn tonnes of laundry detergents in 2019. The penetration rate of laundry detergent in 2019 was about 44% in China, which was much lower than Japan's 79.5% and US's 91.4%. We expect China's laundry detergent market to grow at a rapid CAGR of 13.6% in the next 5 years, reaching a total of Rmb51.5bn in 2024, which implies a sales volume of 3.30mn tonnes.

According to Carbonstop, producing one tonne of laundry detergent can generate about 0.67tonnes of carbon dioxide. We estimate that China's laundry detergent production generated 1.17mn tonnes of carbon emissions in 2019, then this figure might reach 2.21mn tonnes in 2024. As consumption of laundry detergent continues to grow, adopting greener formulas and reducing carbon emissions in the production process can play an important role in achieving carbon neutrality in China.

In the context of rising environmental awareness among global enterprises and consumers, the global giants of personal care products have continuously introduced eco-friendly laundry detergents in recent years. Compared with traditional petroleum-derived laundry detergents, eco-friendly laundry detergents are mainly made from all-natural ingredients, which can reduce the carbon footprint during both production and use.

Tide Purclean: As a world-renowned laundry detergent brand, Tide launched Purclean, a 75% plant-based detergent. Purclean greatly reduces uses of petroleum-derived ingredients without compromising on its cleaning performance.

Seventh Generation's Free & Clear: Seventh Generation is one of the most popular eco-friendly brands in the world. It is a certified partner of Rainforest Alliance and

Forest Stewardship Council, and 97% of its Free & Clear laundry detergent is made from biology-based and plant-based ingredients.

Looking ahead, we firmly believe concentrated laundry detergent will help reduce energy consumption, and lower carbon emissions. According to the *Report on Life Cycle Assessment of China's Concentrated Laundry Detergent* released by China Cleaning Industry Association, if all Chinese consumers switch to concentrated laundry detergents, it can reduce carbon emission by 1.75mn tonnes in the production process and transportation of detergents, and lower electricity consumption by 8.57bn kWh. In addition, this can reduce the discharge of wastewater by 2.42mn tonnes from the consumer-side.

9.3.3.2 Leading Textile and Apparel Companies Take the Lead in Energy Conservation and Emission Reduction

Greenhouse gas emissions during textiles production process are mainly the result of energy consumption, including direct emissions (natural gas, biomass fuel and coal) and indirect emissions (electricity and steam). Fabric production is responsible for most energy consumption. Major waste products include wastewater, exhaust gas and solid waste. Wastewater and exhaust gas are mainly generated in the processes of printing and dyeing.

Shenzhou International, a leading knitwear manufacturer, continues to step up efforts to improve the utilization rate of water and energies in order to lower the adverse impact of production on environment. The introduction of green production process enables products to be eco-friendly.

Pollution discharge: Shenzhou International (Shenzhou) attaches great importance to pollutant control. When selecting suppliers, Shenzhou emphasizes eco-friendliness of raw materials. They continue to improve their production processes to ensure that technologies used are eco-friendly in different production stages. The company adjusts energy mix by using more renewable energy sources. Shenzhou also introduces new eco-friendly equipment to reduce the consumption of resources and discharges of pollutants. All laws and regulations on pollutants discharge are strictly implemented. The company plans to continue make efforts to reduce unit wastewater discharge and waste gas emissions. The company expects its unit wastewater discharge to decline by about 35% in 2020, compared to 2015.

Energy consumption: Shenzhou's Ningbo plant has fully switched over to natural gas as its basic fuel, effectively reducing the adverse impact on the environment. The total consumption of natural gas in 2019 was 59mn m^3, an increase of 61.44% YoY. Total consumption of biomass fuel and coal fell to 174,770tonnes in 2019, which is a decrease of 16.15% YoY.

9.3.4 Recycling

Recycling needs engagements of residents, governments, and enterprises. In this section, we will mainly discuss the optimization of product packaging and the recycling of express delivery packaging. Optimizing packaging is the first step to promote recycling which requires the engagement of the packaging manufacturers. Regarding the recycling of retired products, we will focus on consumer goods manufacturers such as the home appliances industry where recycling and trade-in programs may reduce carbon emissions. The reusage of delivery packaging also needs to engage all stakeholders.

9.3.4.1 Optimizing Packaging is the First Step to Promote Recycling

Reducing plastic use is the most important measure for carbon emission reduction. According to UCSB, if the plastic output growth slows from 4% to 2%, carbon emissions from plastic products in 2050 may decline by 56%.[9] The biodegradable plastic industry has been growing rapidly in recent years. The use of biodegradable plastics in consumer goods packaging can help lower carbon emissions.

Excessive packaging is another issue that needs to be addressed. Excessive packaging is a long-term problem for the *baijiu* industry. Due to the rising environmental awareness among enterprises and consumers, convenient packaged *baijiu* are gradually replacing boxed *baijiu*, and glass bottles are replacing traditional ceramic bottles. In the past 5 years, sales of convenient packaged *baijiu* increased at a CAGR of 20%, and we expect this figure to grow at a CAGR of 15% over the coming 5 years. Compared with ceramic bottles, recycling of glass bottles generates lower carbon emissions, as well. We believe these new trends can help lower carbon emissions from the packaging process.

9.3.4.2 Recycling Needs Active Engagement of Manufacturers

Waste recycling is one of the most direct ways to reduce carbon emissions (Table 9.1). The carbon emissions from the recycling process are usually much lower than those from remanufacturing and landfilling. Studies have shown that depending on types of materials, one tonne of recycled waste can reduce carbon emissions by up to 8.1tonnes. Meanwhile, sorting of plastics can significantly improve efficiency of garbage recycling, which can help reduce unit carbon emissions by 50%–100%.[10]

The replacement of home appliances can help improve energy efficiency of existing ones. Used home appliances contain nonferrous metals, rubber, and toxic

---

[9] Strategies to Reduce the Global Carbon Footprint of Plastics, Zheng et al. Nature Climate Change 9, 374–378(2019).

[10] Greenhouse Gas Emission Factors for Recycling of Source-segregated Waste Materials. D.A. Turner et al. / Resources, Conservation and Recycling 105 (2015) 186–197.

Table 9.1 Contribution of waste recycling to carbon emission reduction

Waste material type	Net CO_2 Eq. per tonne (kg)
Glass	314
Paper	459
Card	120
Books	117
Steel cans	862
Aluminium cans	8,143
Scrap metal	3,577
Mixed plastics	1,024
Mixed plastic bottles	1,084
PET	2,192
PVC	1,549
Wood	444
Light bulbs	779
Fridge and freezers	853
Automotive batteries	435
Vegetable oil	2,759
Composite food	452
Textiles and footwear	3,376

Source Greenhouse Gas Emission Factors for Recycling of Source-segregated Waste Materials. D.A. Turner et al. Resources, Conservation and Recycling 105 (2015) 186–197, CICC Research

substances such as lead and mercury and they may generate a large number of pollutants without proper handling. We estimate that refrigerators, washing machines, air conditioners, and color TVs with a service life of more than 9 years accounted for 11%, 21%, 9%, and 20% of their respective total ownerships in China, implying a total of around 330mn units. So the replacement of home appliances needs active engagement from enterprises and appropriate policies from governments.

Soft drink companies are actively involved in recycling, which may improve the recycling efficiency of PET bottles and reduce carbon emissions. China has a huge demand for soft drink bottles. Given its high economic benefits, recycling of soft drink bottles is already well-established. China's soft drink industry mainly uses disposable PET packaging. According to China Chemical Fiber Website, total demand for PET bottles from China's soft drink industry maintained steady growth in 2017–2019, reaching 4.29mn tonnes in 2019 (Fig. 9.10). Thanks to the wide adoption of recycled bottles, high economic benefits, and sound recycling system, China's recycling rate of PET bottles exceeded 94% in 2019 (a high figure compared by international standards, according to the China Beverage Industry Association, Table 9.2). However, China's recycling market still has significant potential in its recycling technology and efficiency.

Fig. 9.10 Demand for PET bottles from China's soft drink industry and YoY growth in 2017–2019. *Source* ccf.com.cn, IPO prospectus of CR Chemical Materials, CICC Research

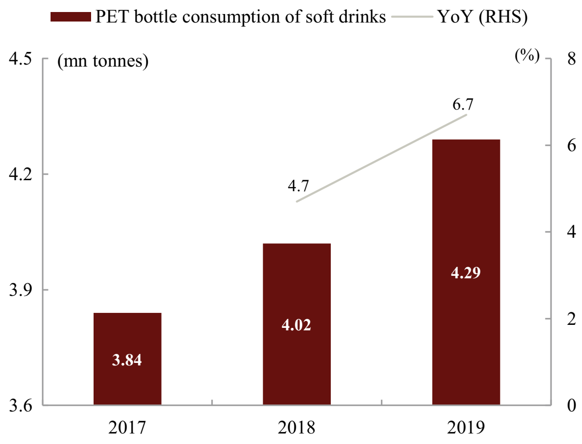


Table 9.2 Recycling rates of PET drink packages by country and region in 2019

Country	Package types	Recycling rate (%)
China	PET bottle	>94
Germany	Can, PET bottle, glass bottle	97
The Czech Republic	Beer and soft drinks bottle	99
Finland	Can, PET bottle, glass bottle	93
US (varies among states)	Beer and soft drinks bottle	50–85
Norway	PET bottle	95
Denmark	Can, PET bottle, glass bottle	89
Sweden	Can, PET bottle	84, 81
	Glass bottle	93
Belgium	PET bottle	>85
Japan	PET bottle	92
Switzerland	PET bottle	82

Source China Beverage Industry Association, Chinese Research Academy of Environmental Sciences, The Council for PET Bottle Recycling of Japan, CICC Research

Nongfu Spring plans to collect and recycle 1mn 19L packaging bottles each year. These bottles will be remanufactured into plastic products. In addition, international soft drink giants have begun to focus on carbon reduction actions in recent years by using more recycled PET to manufacture beverage packaging.

The packaging of rice, flour and oil mainly made with PET plastic bottles and plastic woven bags in China. The current recycling rate for those packaging is low. According to Recycling Plastics Branch of China National Recycling Resources Association, China Packaging Federation, and Euromonitor, the recycling rate of PET plastic bottles for cooking oil in 2019 was about 83% in China, compared to 85% in Europe and 93% in Japan. The recycling rate of plastic woven bags for rice and flour in 2019 was about 24% in China, compared to 42% in Europe and 47% in Japan. There are many reasons behind the low recycling rate of plastic woven bags for rice and flour, including difficulty in sorting, high recycling cost and inefficient recycling system. The active engagement of enterprises may help increase the recycling rate.

9.3.4.3 Reusing of Express Delivery Packaging

Although package delivery service is gradually more convenient than before, delivery packaging has brought several challenges to urban cleaning and environmental protection, including the low recycling rate of delivery packaging (less than 20%), redundant packaging and the low utilization rate of degradable garbage. Targeted measures such as "3R1D" were adopted to reduce the utilization of express packaging. The three Rs are the abbreviations of "Reduce", "Reuse" and "Recycle", while the "D" is the abbreviation of "degradable".

Reduce: The volume and weight of packaging materials should be minimized in order to lower resource consumption. For example, reducing the redundant packaging of e-commerce parcels (zero secondary packaging by 2025) and increasing the filling rate of packages through smart packaging algorithm.

Reuse: Packaging materials should be reused to the maximum level in order to reduce the consumption of disposable materials. According to China's State Post Bureau (SPB), 2mn recyclable shipping boxes were put into use and utilization rate of recyclable transit bags reached 75% in 2019. The SPB estimated that the scale of recyclable express delivery parcels will reach 10mn by 2025.

Recycle: The wasted express delivery packaging materials can be recycled into new packaging materials through reproduction. For example recycled corrugated paper can be recycled into produce pulp.

Degradable: Degradable plastics can be used to replace disposable plastics. The most popular degradable materials are plant-based plastics and Polylactic acid.

9.3.5 Sharing Economy

With the emergence of the sharing economy as a hot topic for startups over the past two or three years, many new business models have emerged. While the umbrella sharing and toy sharing systems have disappeared and the popular bicycle sharing system is waning, the once-obscure power bank-sharing is beginning to dominate the Chinese market. The sharing economy epitomizes a lifestyle philosophy that values renting and sharing. As the sharing economy matches productivity with consumption demand more efficiently, it can save resources and support a low-carbon economy.

The power bank sharing system has reduced Chinese consumers' purchase of power banks, thus reducing the carbon emissions caused by power bank productions. According to China Internet Network Information Center (CNNIC), China has 932mn mobile internet users. Without the power bank sharing system, assuming every mobile internet user owns one power bank and the average replacement cycle is three years, we estimate that the annual demand for power banks may reach 300mn. According to iResearch's statistics, in 2019, the number of the shared power bank users was nearly 250mn and the transaction amount reached about Rmb8bn. This means that users spend Rmb32 on shared power banks on average. As each user spends Rmb1–1.5 each time they use shared power bank, it is estimated that they use shared power banks 20–30 times. On average, shared power banks are rented out 0.8 times per day, indicating that there are 20–30mn power banks in the market.

In addition to power bank sharing, many other business models of the sharing economy help reduce carbon emissions by more efficiently meeting people's production and living needs. These business models include ride sharing, workspace sharing, and study room sharing.

Different sharing economy business models centralize the originally scattered and individualized needs. This can minimize unnecessary production, improve production efficiency created by the economies of scale, and create a lower-carbon production model that requires larger upfront investment, thus further reducing carbon emission.

For example, WeWork offices are usually located close to metro stations with the purpose of encouraging low-carbon travel. Additionally, WeWork adopted an intelligent booking system for all meeting rooms and remote meetings are encouraged to reduce emissions. And all office supplies should switch to digitalized products or use recyclable materials. In the future, thanks to further exploration of demands for sharing economy, model innovations and technological progressions, we believe that social production methods will become low carbon and energy-saving.

9.3.6 Environmental, Social, and Governance (ESG) Development

ESG refers to an investment philosophy and evaluating standards that pay attention to the environmental, social and governance performance of enterprises. It helps evaluate the contribution of an enterprise to sustainable economic growth and social responsibility (Fig. 9.11).

ESG pushes enterprises to pursue not only the maximum self-interest but also maximum social interest. Companies with good ESG performance can better anticipate and manage opportunities and risks from economic condition, environmental problems and social changes for now and in the future. They pay more attention to

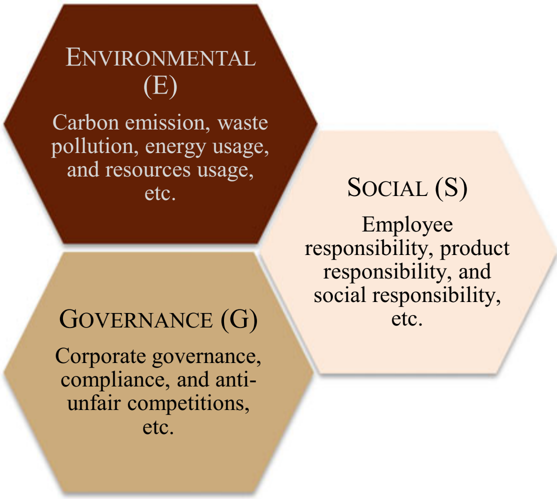


Fig. 9.11 ESG of consumer goods companies. *Source* CICC Research

quality, production innovations, environmental protections, energy saving and carbon emission reductions. These can lower operating costs, create competitive advantages and generate long-term values. China's leading home appliance companies have made substantial progress in the fields of energy-saving, emission reduction and waste recycling.

Midea and Haier have won recognition from overseas investors because of their emphasis on ESG performance, which were fully disclosed in their social responsibility reports. Haier's energy consumption per unit of output value in 2017, 2018, and 2019 dropped by 13.22%, 16.67%, and 6.77% year-on-year(YoY), and carbon dioxide emissions were reduced by 44,221tonnes and 10,503tonnes in 2018 and 2019. Haier Smart Energy Center uses automation and information technologies with central management model to dynamically monitor and digitally control water, electricity and natural gas consumption in all factories. The center automatically controls energy conversion, transportation, distribution and consumption and accurately collects energy data to predict, analyze and optimize energy consumption.

9.4 Policy Formulation and Social Governance: Comparing China with Other Countries to Identify Future Directions

9.4.1 Home Appliances: Energy Efficiency Standards, Energy-Saving Subsidies and Recycling Systems Need to Be Improved

China's current entry-level energy efficiency standards for home appliances are about 20% lower than those of the US, Europe, and Japan (statistical methods and dimensions not completely comparable).[11]

For air conditioners, refrigerators and washing machines, the US has introduced the mandatory Energy Guide label (under the supervision of Department of Energy) and the voluntary ENERGY STAR label (under the supervision of Environmental Protection Agency).

The European Union Directive (EU) No. 626/2011 requires that air conditioners with a rated cooling capacity equal or greater than 12kW must be affixed with an energy efficiency label. This energy efficiency label is required to indicate the annual power consumption. The EU has also enacted similar regulations on refrigerators and washing machines.[12]

Japan's energy efficiency standards for household appliances mainly include the quasi-mandatory Top Runner Program, mandatory energy-saving labels for electrical appliance retailers, and voluntary energy-saving labels.

Having analyzed energy efficiency standards for air conditioners and refrigerators in Japan and the US, we find that the minimum energy efficiency standards for home appliances in developed countries are about 10%–30% higher than that of China (statistical methods and dimensions not completely comparable).

Subsidies can help promote energy-efficient home appliances. Between 2009 and 2013, China's household air conditioner industry experienced two rounds of subsidies for energy-efficient products and two rounds of energy efficiency standards upgrades. Historical experiences indicate that these subsidies can help manufacturers and consumers switch to energy-efficient products smoothly. On 10 February 2021, the Ministry of Commerce called for expanding the sales of energy-efficient home appliances and green products. We believe that moderate energy-saving subsidies can enhance the competitiveness of energy-efficient products, thereby improving the

[11] China, US and Japan have different classifying standards. Some of the measurements used in these classifying standards are not comparable. For example, air conditioner classifying standards in China use APF measurement while the US uses EER measurement. These two measurements are not comparable.

[12] The Commission Directive 94/2/EC of 21 January 1994 implementing Council Directive 92/75/EEC with regard to energy labelling of household electric refrigerators, freezers and their combinations; Delegated regulation 2010/1061 - Supplement to Directive 2010/30/EU with regard to energy labelling of household washing machines Text with EEA relevance.

energy efficiency structure of home appliances, and helping China achieve carbon neutrality as soon as possible.

In addition, numerous countries have developed carbon footprint assessment standards to encourage the production and consumption of low-carbon products, and quantify the greenhouse gas emissions of products by "carbon labels". For example, the international standard ISO/TS14067 and the British Standards Institution's PAS2050 are two widely-used carbon footprint accounting and certification standards. "Carbon label" is a voluntary certification index, which can help companies establish a positive corporate image of low carbon and environmental protection, attract more consumers who are concerned about climate change, and enhance competitiveness of products in the international markets that have stricter environmental laws and regulations.

Environmental protection requirements include:

The US federal government has passed the *Toxic Substances Control Act (TSCA)* and state governments have passed other relevant laws and regulations.

Products in the EU market need to meet the electronic waste recycling requirements listed in the EU's *Waste Electrical and Electronic Equipment (WEEE) Directive*. For example, the recovery rate of temperature exchange devices, including air conditioners, refrigerators, freezers and others, must reach 85%. And the reuse and recycling rate must reach 80%. The products also need to comply with the hazardous substance control requirements in the *Restriction of Hazardous Substances (RoHS) Directive* and the ecological design requirements in the *Energy-related Products (ErP) Directive*. In addition, there are voluntary eco-labels, such as the EU Ecolabel that applies to refrigerators, washing machines, dishwashers, and vacuum cleaners, and the Nordic Swan Ecolabel that applies to refrigerators, washing machines, and kitchen appliances.

In Japan, air-conditioners, refrigerators, and washing machines need to meet recycling requirements for waste home appliances in the *Home Appliance Recycling Law*. Air-conditioners, refrigerators, washing machines, dryers and microwave ovens also need to meet the hazardous substance control requirements stipulated by J-MOSS.

While establishing environmental protection standards, China also continues to improve its used home appliance recycling system:

In 2012, China introduced *the Administrative Measures for the Collection and Use of Waste Electrical and Electronic Product Disposal Fund*, establishing a fund to subsidize companies that dismantle and dispose of used home appliances. However, the fund has a large funding gap due to insufficient budgets and cannot meet actual needs.

In May 2020, China introduced the *Implementation Plan on Improving the Waste Home Appliance Recycling and Disposal System to Promote Home Appliance Replacement Consumption*, encouraging home appliance manufacturers to develop self-owned recycling networks, commissioned recycling, joint recycling, and new internet-based recycling models, as well as to launch trade-in programs.

In December 2020, China issued the *Action Plan on Actively Building a Waste Home Appliance Recycling and Disposal Industry Chain to Promote Home Appliance Replacement Consumption.*

9.4.2 Furniture: Promote Sustainable Use of Forest Resources

The EU and the US imposed strict supervisions over logging and the production of wooden products, and promulgate relevant laws and regulations to promote the sustainable use of forests and avoid excessive logging and timber consumption.

On the global level, the FSC forest certification (FSC stands for Forest Steward Council, a non-profit international organization initiated by the World Wide Fund for Nature) aims to ensure a sustainable operation of the forestry production industry chain and encourage the public to purchase standardized forest products to improve forest management, promote sustainable use of forests and avoid excessive logging and consumption.

The EU and the US have also issued corresponding laws and regulations. For example, both *Lacey Act Amendment* and the *European Union Timber Regulation* require relevant documents to prove the legality of the source of timber, and impose severe punishments on illegal trading of wooden products.

9.4.3 Packaging: Overseas Experience and the Overcoming of Difficulties

9.4.3.1 Product Packaging: Comprehensive Regulation is Imperative

China has issued multiple documents to regulate product packaging. In 2014, the General Administration of Quality Supervision, Inspection and Quarantine and the Standardization Administration issued the *General Rules for Restricting Excessive Packaging of Goods*, promulgating requirements on packaging costs, materials, and design. Many local governments have followed suit.

In recent years, the central and local governments, food delivery platforms and catering companies have adopted plastic reduction measures to support sustainable development.

In terms of the use of plastic packaging, the National Development and Reform Commission (NDRC) and the Ministry of Ecology and Environment (MEE) issued the *Opinions on Further Strengthening the Control of Plastic Pollution in 2020*. According to the document, the use of non-degradable plastic bags shall be prohibited by the end of 2020 in shopping malls, supermarkets, pharmacies, bookstores, as well as food delivery services and exhibition activities in urban areas of municipalities, provincial capital cities, and cities under separate state planning. Additionally, the consumption intensity of non-degradable disposable plastic tableware in the food delivery industry should be reduced by 30% by 2025 in cities above the prefecture level. In terms of plastic packaging recycling, Xiamen introduced new rules for garbage classification in July 2020, reclassifying disposable plastic lunch boxes, plastic bags from "other garbage" into "low-value recyclables" and including them in the recycling system.

Globally, plastic restriction policies are becoming stricter. With the rise of global awareness of environmental protection and emission reduction, developed economies such as the EU and the US are continuously tightening their regulations over plastic packaging products and restricting the use of plastic packaging. The Chinese authorities can improve existing systems and regulations based on international experience. For example, the EU has banned the production and sale of disposable tableware and other disposable plastic products from 2021, and replaced them with paper, straw, or reusable hard plastics. The UK announced in 2019 that it would introduce a tax on various plastic products. Japan has a higher recycling rate of PET bottles and rice/flour plastic woven bags than China, which helps the country reduce carbon emissions (Fig. 9.12). We attribute this to Japan's strict regulations, comprehensive and meticulous recycling system, and mature technologies.

Strict regulations lay the foundation for packaging recycling. Japan has formulated a number of regulations on packaging recycling. The country promulgated the *Waste Management and Public Cleansing Law* in 1970 and the *Container and Packaging Recycling Law* in 1995, and established a "Reduce, Reuse, Recycle" policy framework, stipulating that PET bottle manufacturers and food manufacturers using PET bottles need to bear the cost of recycling.

Japan's comprehensive and meticulous recycling system becomes a formidable force. A recycling system for plastic products in Japan has been in place for decades.

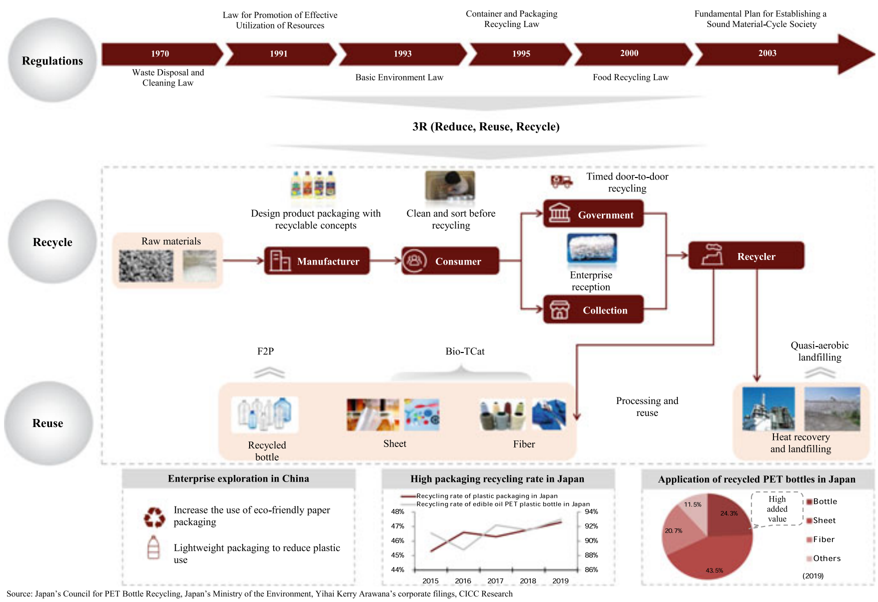


Fig. 9.12 Japan's recycling experience. *Source* Japan's Council for PET Bottle Recycling, Japan's Ministry of the Environment, Yihai Kerry Arawana's corporate filings, CICC Research

Waste plastic packaging is cleaned in advance by residents. It is sorted and recycled by government-designated personnel or recycled through various collection points. Then recycling companies carry out heat recovery, landfill treatment, processing and reuse.

Mature reusable technologies can help. Japan's waste plastic reuse technologies mainly include mechanical treatment and chemical degradation. 24% of the recycled plastic waste is used to produce high value-added bottles. Japan uses F2P and BioTcat technologies to keep chemically degraded molecules tough and safe for food, thereby realizing the reuse of plastic waste.

The deposit refund system in Germany is a model of efficient recycling of PET bottles. At present, the mainstream international method for recycling of PET bottles is the deposit refund system, which has been adopted by Western European countries, Canada, and some states in the US. Germany's deposit refund system was approved by legislature in 1991 and implemented in 2003, mainly for various beverage packaging, such as PET bottles, aluminum packaging, and glass. We believe Germany's recycling system possesses the following advantages:

Clear rights and responsibilities: The system lays out the responsibilities of manufacturers, retailers, and consumers to contribute to the circular economy.

Digital supervision and management: The operator established by the retail and manufacturing industry associations supervises and maintains the system and monitors the overall process digitally.

High level of automation: In the recycling system, 80% adopts automatic recycling and 20% adopts manual recycling.

Large-scale reuse: Their reprocessing process achieves economies of scale.

As one of the first countries to establish a deposit refund system, Germany has achieved a high PET recycling rate by virtue of this system, and has increased the proportion of PET bottles made from recycled materials leveraging an efficient reuse system (Fig. 9.13). According to GVM, the recycling rate of PET bottles in Germany was 97% in 2015, the utilization rate was 93.5%, and about 34% of the recycled bottles were reprocessed into PET bottles, much higher than the world average (less than 10%).

9.4.3.2 Delivery Packaging: Difficulties and Breakthroughs

China has been steadily promoting green delivery packaging, and has issued the *Interim Regulations on Express Delivery* and the *Opinions on Accelerating the Green Transformation of Express Delivery Packaging*. However, we still see obstacles in the industry's green transformation.

There are standards for packaging reduction but it is difficult to implement. In 2018, the General Administration of Quality Supervision, Inspection and Quarantine and the Standardization Administration issued national standards for delivery packaging supplies, putting forward requirements for reduction of delivery packaging. However, the porosity and volume ratio in the standards are difficult to determine

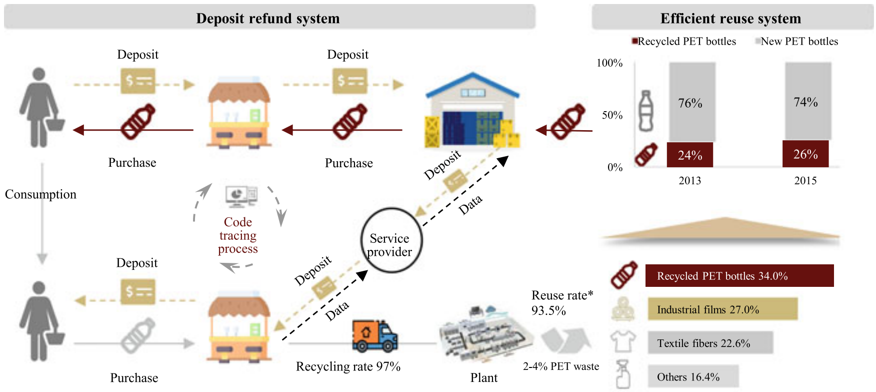


Fig. 9.13 Germany's deposit refund system for recycling of PET bottles and its efficient reuse system. *Note* All are 2015 data. *93.5% refers to the PET utilization rate after removing the caps and labels. *Source* CM Consulting, GVM, Forum PET, CICC Research

with the naked eye, while random inspection of delivery companies would be too inefficient.

Recycling requires the cooperation of the government, manufacturers, logistics companies, and the public. In China, there is currently no systematic recycling path. Elderlies, cleaning staff and scavengers remain the main force of recycling. Package delivery companies have gradually initiated recycling actions in recent years, but the overall recycling efficiency is not high. The establishment of a large-scale recycling system needs to adopt a multi-pronged approach and refer to the experiences of Germany and Japan.

Both Germany and Japan have enacted relevant laws. Germany introduced the packaging waste management measures and the packaging recycling law, setting recycling targets and time limits for different packaging waste. Japan enacted the energy protection and recycling promotion law and the packaging recycling law to build a recycling system. People's awareness of waste classification is the foundation of the recycling system of these two countries. Both countries have implemented strict household waste classification mechanisms.

Both countries make clear the recyclers and responsible parties. Germany requires packaging material manufacturers to register with the Green Dot, the country's dual system of waste collection, and pay Green Dot fees. Japan has built a large number of recycling sites to make recycling convenient, and encourages residents to participate in collective recycling.

We suggest that China establishes an express delivery packaging recycling system by taking the following actions:

Strengthening laws and regulations on packaging waste management. There are only a few general rules for waste disposal, which only result in relatively minor penalties.

Raising the public's awareness of recycling: China should promote the idea of packaging recycling through media communication, corporate activities and other methods. It should also implement waste classification in major cities in an appropriate time.

Improving the recycling system: China should make clear the main recycling channels such as campus, community and office. It should also enrich recycling channels such as convenience stores, express delivery outlets and community property management firms, as well as deploy recycling infrastructures such as recycling bins and express delivery cabinets.

9.4.4 Catering: Promote "Clear Your Plate" Campaign and Organic Food Waste Reusing

In recent years, China has strengthened anti-food waste education and propaganda, and catering companies have taken measures to help reduce food waste. At present, China mainly relies on education and publicity to reduce food waste. The CPC Central Committee and the State Council issued *the Regulations for Party and Government Agencies to Practice Economy and Oppose Waste* in November 2013, promoted the "Clear Your Plate" campaign through posters and TV screens or advertising screens? and encouraged ordering and cooking food on demand. The central government's call against food waste received positive responses from consumers and catering companies. In 2013, the official reception and catering expenditures of central government agencies fell 60% and kitchen waste declined more than 30%.

Looking forward, we believe legal control and technological innovation will help reduce the environmental impact caused by food waste. Foreign countries control food waste mainly through policies, laws and recycling, in an combination with education and publicity. In terms of policies and laws, France introduced the anti-food waste law in 2016, stipulating that supermarket donating food that is about to expire will receive a tax credit equal to 60% of the value of the donated food, and restaurants destroying edible unsold food will face fines of up to 0.1% of the revenue in the previous fiscal year. In terms of recycling, kitchen waste is used for composting and fermentation in countries such as the UK, the US, and Japan. For example, US company Re-Nuble converts organic waste such as kitchen waste into organic fertilizers, and develops soilless cultivation techniques to grow new crops. Another US company Ecovative Design uses plant fibers from wasted mushrooms and other discarded organic crops to manufacture strong, easily degradable packaging materials.

9.5 Quantitative Calculations: A Green Lifestyle Is of Great Significance

In order to better understand the positive impacts of residents' green lifestyles and consumption habits, companies' active participation, and the government's guidance and promotion on carbon neutrality, we made feasibility assumptions and quantitative calculations on carbon emission reduction that can be achieved by five typical measures: Electricity saving, "Clear Your Plate" campaign, low-carbon diet, delivery packaging recycling, and shared power bank. The results from this model show that the promotion of green lifestyles is of great significance to carbon neutrality.

9.5.1 Electricity Saving and Use of Clean Energy

The growth of carbon emissions from household power consumption can be effectively controlled by promoting the improvement in energy efficiency of home appliances and the increase in the proportion of clean energy compared with the baseline situation (where energy efficiency of home appliances and the proportion of clean energy stay the same). With the improvement in energy efficiency of home appliances and the increase in the proportion of clean energy, carbon emissions from household power consumption in 2030 will be 810mn tonnes, a decrease of 494mn tonnes compared to the baseline situation, with the former accounting for 57% of the emission reduction and the latter for 43%. And with the improvement in energy efficiency of home appliances, household power consumption in 2030 will be reduced by 21% compared to the baseline situation.

To reverse the upward trend of carbon emissions from household power consumption, the rate of increase in the proportion of clean energy needs to be further accelerated. We currently assume that the proportion of clean energy will increase from 34% in 2020 to 46% in 2030.

With the improvement in energy efficiency of home appliances, we estimate that household power consumption will grow at a 3.3% CAGR over 2020–2030, 2.5 ppt slower than the baseline situation; household power consumption in 2030 will be 1,513.8bn kWh, 21% lower than the baseline situation.

9.5.2 Reduction in Food Waste

According to the 2018 China Urban Catering Food Waste Report issued by the World Wide Fund for Nature (WWF) and the Institute of Geographic Sciences and Natural Resources Research, CAS, the amount of food waste in China's urban catering industry reached 17–18mn tonnes in 2015.

We assume that: (1) If no measures are taken to reduce food waste, the amount of food waste in urban catering will grow at a 10% CAGR over 2016–2030, largely the same as the growth rate of urban catering consumption. (2) The structure of food waste in urban catering in the future is consistent with the data in the *2018 China Urban Catering Food Waste Report*. (3) For carbon emissions of major foods, we refer to *A Comparative Study on Carbon Footprints between Plant- and Animal-based Foods in China.*

With the promotion of reduction in urban food waste, we assume that the waste will be reduced by half by 2030, and we estimate that corresponding carbon emissions will be reduced by 26.91mn tonnes.

9.5.3 Changes in Dietary Structure

We assume that: (1) 10% of the population will switch from omnivorous diets to ovo-lacto-vegetarian diets, with reference to *Environmental Impact of Omnivorous, Ovo-lacto-vegetarian, and Vegan Diet*. (2) The remainder of the population will use pork and chicken to replace half of their beef and mutton intake. (3) The remaining food intake structure will remain unchanged. (4) According to the forecast using data from the Food and Agriculture Organization of the United Nations in 2018, Chinese population will reach 1.464bn in 2030. (5) For carbon emissions of major foods, we refer to *A Comparative Study on Carbon Footprints between Plant- and Animal-based Foods in China.*

If the Chinese dietary structure in 2030 changes align with our assumptions, we estimate that corresponding carbon emissions in 2030 will be reduced by 66.21mn tonnes.

9.5.4 Recycling of Express Delivery Packaging

Package delivery business volume will continue to grow rapidly in the next few years, and the consumption of packaging material will grow accordingly with package delivery business volume. Parcel volume will reach about 164.4bn in 2025, implying a CAGR of 18.3% over 2018–2025. And the consumption of packaging material will reach 27.46mn tonnes in 2025, accounting for 8% of urban domestic waste collection and transportation volume.

The disposal of delivery packaging through incineration and landfill generates a significant amount of green house gases, especially carbon dioxide, since packaging material is mainly made out of paper or plastic. If the current recycling rate (below 20%) remains unchanged and reusable delivery boxes are not applied, carbon dioxide generated from the disposal of express delivery packaging (largely landfill and incineration) is expected to increase from 5.27mn tonnes in 2018 to 15.36mn tonnes in 2025, a CAGR of 16.5%.

However, if delivery packaging can be reduced, reused and recycled, we believe corresponding carbon emissions will be reduced significantly.

We assume that by 2025: (1) China's delivery packaging recycling system will improve and the recycling rate will rise to 40%; (2) reduction of redundant packaging and intelligent algorithms will reduce packaging per parcel by 15%; and (3) the number of reusable express delivery boxes will reach more than 10mn. Under these assumptions, carbon dioxide emissions from the disposal of express delivery packaging in 2030 will be reduced from 15.36mn tonnes by 32.2% (or about 4.94mn tonnes) to 10.42mn tonnes, with the increase in recycling rate contributing 61% of the emission reduction.

9.5.5 Shared Power Bank Help Reduce Purchase Demand

The stock of shared power banks will further expand, as their penetration of major business venues, the number of users, and the times of usage per capita increase. Shared power banks meet the charging needs of users and restrain individuals' purchase demand for power banks. Assuming that there is no breakthrough in charging technology, we estimated the reduction in demand for power banks in the next five years due to the growing use of shared power bank. Considering the reduction in outdoor activities in 2020 due to the pandemic, we make assumptions based on the situation in 2019. Shared power banks are used frequently and their efficiency generally drops significantly after 500 charges assuming that the replacement cycle is 1.5 years.

Shared power bank will reduce the average annual consumption of power banks in the next 10 years by about 100mn units. Because the specific energy consumption of producing a power bank is not available, we use China's data on carbon dioxide emissions per unit of GDP, i.e. 0.14tonnes per Rmb1,000 of GDP. Assuming that the average price of power banks is Rmb50/unit, shared power banks will reduce the average annual carbon dioxide emissions in the next 10 years by about 700,000tonnes.

Chapter 10
Green City: Towards Low-Carbon Urban Planning and Governance

Abstract Green city is a development concept that has been widely embraced by the international community, especially by metropolises. In a broad sense, "green" indicates a city's overall habitability, in terms of environmental health (pollution prevention and control, carbon emissions, and air quality), public space design (environmental aesthetics and a city's vitality), equality of the social resource distribution (housing supply and wealth inequality), transportation efficiency (green commuting), and sustainability of energy consumption (efficient use of renewable energy sources). China is facing a series of issues as it heads towards its green city vision. From the perspective of spatial planning, we believe high carbon emissions are fundamentally resulted from outdated construction methods due to inefficient land use and housing supply–demand mismatch, and long commutes for workers caused by the separation of residence from workplace. From the perspective of technologies used in the construction and maintenance of transportation facilities, we believe that the penetration of alternative-fuel vehicles (AFV) in public transport remains low, and the lack of profitability of urban rail transit is a problem that should be urgently addressed. New technologies and techniques are needed to reduce energy consumption and carbon emissions from the production of building materials and the construction and operation of buildings. The use of aging water and heat supply facilities leads to high loss rates. Meanwhile, China's resource recovery sector is still in its infancy, and the reliance on human labor to offer services such as waste sorting points to room for operating efficiency enhancement. This chapter discusses the goal of building green cities in the context of carbon neutrality, outlines possible policies and measures to address the above-mentioned issues, and quantifies the carbon emission reduction achieved by optimizing systems for urban planning and housing supply, and adopting new technologies.

10.1 Problems and Challenges Facing China in Its Green City Vision

Globally, cities such as Vancouver, Melbourne, Toronto, Copenhagen, and Rotterdam have made remarkable progress in their green city development, especially in terms

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_10

of energy conservation, emission reduction, and the overall consideration of environmental issues during the urban planning process. Several factors have contributed to their success, including the early adoption of sustainable development visions, the effectiveness of their environmental policies, and their improving industrial structures. Cities with stronger industrial vitality such as London, Paris, New York, Tokyo and Singapore are also taking the lead in green city development, which represents an important component of a city's "soft power". We have noticed many similarities between these cities: (1) preliminary urban planning (comprehensive urban planning focusing on sustainability in the long term, corresponding with long-term development goals, and adopting to extensive public feedback); (2) widespread support among the public; (3) continuity and integration of macro policy and city planning regulations; and (4) establishment of effective supervision mechanisms.

Green technologies utilized in urban planning are mainly related to transportation, municipal facilities, ecological land use, and construction engineering. We believe the experience from other countries is instructive for China, and will help China address problems of its emerging "urban diseases". Furthermore, the development of livable cities with more environmental-friendly facilities and a more sustainable atmosphere fundamentally echoes the pursuit of *la dolce vita* for Chinese people.

Two major challenges confronting China in its process towards green cities are improving the overall spacial structure of cities and promoting the technological developing in related fields. Nowadays, most urban planning for major Chinese cities still fits into the "monocentric city" framework, which has caused the following issues:

1. Inefficient urban land use—e.g. inefficient use of industrial land, the separation of residence from workplace, and the mismatch between housing supply and demand.
2. Inefficient transportation system. The overall transportation planning efficiency as well as the coverage and accessibility of public transport facilities still need improvement.
3. Insufficient construction technology improvement and lack of management methods for existing building. At present, building management and maintenance in China consumes high quantities of energy and generates heavy pollution, especially a large volume of carbon emissions in the process of building materials production and the building construction. The standard for the management of buildings throughout their life cycles is not yet in place.
4. Inefficient city operation and maintenance. The idea of environmental protection and sustainable development has been more widely promoted in China in recent years, but problems remain in fields such as water/heat supply, resource recycling, and waste sorting.

We believe that several factors including spatial arrangements, formulation of policies and regulations, technology application, standard setting, and public participation in city planning should be better coordinated in order to address the above problems. Given the increasingly strict control over new land quotas for building

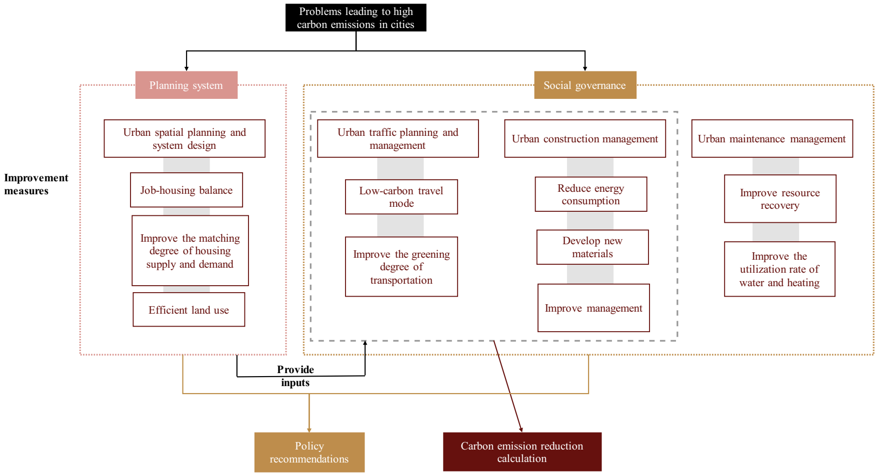


Fig. 10.1 Structure of this chapter. *Source* CICC Research

construction, we believe China needs to find a balance between expectations and realities to achieve its sustainable urban development goals.

In order to achieve the green city vision, we believe future urban planning should be based on: (1) the current development stage of the industrial economy, and the environmental governance goal; (2) coordination between the industrial development and infrastructure construction; and (3) optimization of spatial arrangements and management skills of urban development. This chapter discusses possible solutions to the abovementioned problems from four perfectives: (1) urban spatial planning (addressing issues such as inefficient land use, separation of the residence from workplace, and housing supply–demand mismatch); (2) urban transportation planning (promoting low-carbon commuting); (3) urban construction management (addressing the issue of using energy-consuming construction technologies and environmentally harmful building materials as well as improving the management of existing buildings): and (4) urban maintenance and management (promoting efficient water usage and waste recycling). See Fig. 10.1 for the structure of this chapter.

10.2 Urban Spatial Planning: Building Cities with Sufficient Housing Supply and Evenly Distributing Residences and Workplaces

Cities are major sources of carbon emissions, which are mainly generated by following 3 factors: (1) residents' reliance on private cars for long-distance commuting due to the spatial separation between residence and workplace as well as the uneven distribution of urban resources (e.g., restaurants, entertainment facilities, supermarkets and hospitals); (2) the mismatch between housing supply and demand; and (3) low-density construction in built-up areas. This chapter discusses possible countermeasures from the perspectives of urban spatial planning and institutional design, and suggests methods for calculating carbon emissions reduction in following sections.

10.2.1 Evenly Distributing City Resources to Reduce Commuting Distances

Developing multiple business centers and creating 15-min community life circles. The majority of mature and emerging cities in China are suffering from "urban disease" as a result of the monocentric city model. Due to the concentration of urban resources in a single core area, residents living in the suburbs have to suffer long commutes to work. The cost of long-distance commuting increases the value of residences and living space in the core area which increase market prices of these residences and forcing some people to move to the suburbs. This further exacerbates the uneven distribution of urban resources leading to high carbon emissions and low traffic efficiency. In order to reduce urban carbon emissions by shortening the average commuting distance, we believe it is important to create multiple business centers and 15-min community life circles.

Switching from the single-core to the multi-core city model. The even and fair redistribution of urban resources in a city is the key to addressing the issue of spatial separations between living and working areas, and it can eventually leads to shorter commutes. We believe that the following should be considered in future urban planning:

- **Promoting multi-core city model development and improving the rapid transit system.** We believe developing subcenters based on traffic locations, industrial bases, and economic connections between city cores is more likely to bring capital to high-quality industries which can boost economic growth in the short- and medium-term. On the other hand, a rail transit network is important for a city's sustainable development. Rail transit network needs to be extended to suburbs to strengthen economic linkages between urban centers and subcenters. Inter-city rapid transit systems should also be encouraged between major cities such as Beijing and Shanghai to strengthen economic interconnectivity with surrounding satellite cities.
- **Encouraging mixed-use urban planning ideas**. We believe large- and medium-sized cities should focus more on urban planning in order to unleash potential of the limited land resources. While ensuring land resources for different uses are reasonably allocated, we believe governments should consider adding more functions to the previous single-purposed lands during the planning process. On the other hand, government should pay more attention to "fill-in" the structures of existing

construction land and to revitalize these areas by renovating and upgrading old residential communities, factories, commercial buildings, and other supporting facilities.

Building 15-min community-life circles by better allocating basic service facilities. Reasonable allocation of urban resources surrounding the residential area is important to build 15-min community-life circles that can fulfill the residents' needs for consumption, entertainment and social life. Two issues should be considered when building 15-min community-life circles:

- **Efficient combination of facilities for walking, cycling and public transport**. Cities should provide transportation facilities based on walking distance so that residents have various options to reach their destinations (walking, cycling and public transport) within a 15-min community-life circle. The availability of transport options will help reduce the use of private cars to reduce traffic jams during rush hours. Moreover, during urban planning and designing, it is necessary to construct supplementary facilities in residential areas to satisfy basic service needs of residents. The locations of these service facilities should be selected based on the principle of covering wider range of residents and areas.
- **Compact and diversified arrangement of business structures**. Under the transit-oriented development (TOD) model, properties within the 15-min life circle needs to be compactly arranged to include all the necessary resources for various daily life scenarios (e.g. residence, shopping, medical care, entertainment, and socializing). This compactness is not only reflected in the compression of distance and efficient use of space, but also in the diversification of services provided. Urban planners also need to consider the varying demand for daily services across different income groups.

Taking the above-mentioned urban planning strategy as the future adjustment path, we calculate the possible reduction of urban commuting distance in some major cities in China, and use the result as a basis to calculate the carbon emission reduction in urban traffic management segment. Assuming residence and workplace are evenly distributed in 36 selected major cities, we estimate that the average commuting distance will decrease to 115.3bn km (adjusted to 83.7bn km after considering some uncontrollable factors in urban planning).

From the perspective of urban planning, there are two types of commutes: (1) Commutes caused by the separation between residential areas and the workplace. Excluding individual preferences for employment and the location of residences, we assume that if everyone worked as close to home as possible, it would minimize the average commuting distance. According to data from China Academy of Urban Planning and Design (CAUPD), we estimate that 30–60% of the commuting distances are caused by the separation of residence from workplace (Fig. 10.2). (2) Extra distance caused by the discrepancy between individual preferences for the location of workplaces and residences.

International urban planning scholars have noted that a reasonable commuting distance for walking and biking is 1–2 miles (1.6–3.2 km). Although cities have been profoundly changed by economic development and technological advances,

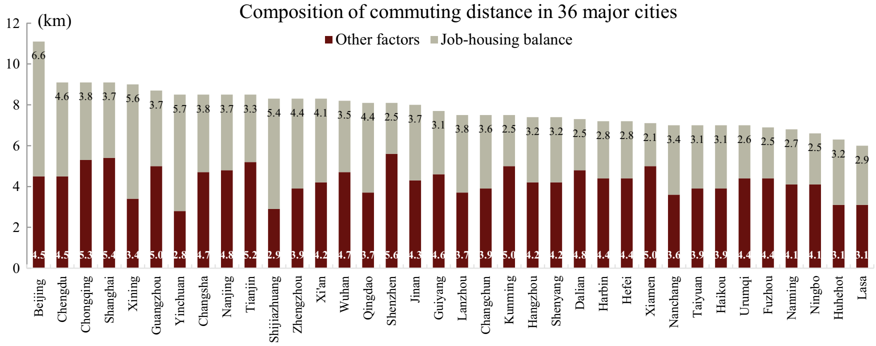


Fig. 10.2 We estimate that 30–60% of the commuting distances in 36 major cities are caused by the separation of residence from workplace. *Source* 2020 Monitoring Report on Commuting in Major Cities by CAUPD, CICC Research

we believe the commuting distance proposed by the scholars remains valid today. We believe measures, such as building multi-centric cities and 15-min life circles, can help reduce the commuting distance to the suggested range, and we can calculate the decline of commuting distance for each employee when the residence and workplace are evenly distributed from the perspective of urban planning. Nearly 70% of the Chinese population worked in cities at end-2019, of which our calculation of commuting population in 36 select cities is based. We estimate that the even distribution of residence and workplace can reduce total commuting distance in these cities by around 115.3bn km per year. Considering the difficulty of urban planning adjustments varies for cities at different development stages, we classify cities into super-large, extra-large, large and medium-sized based on population size and average commuting distance, and set breakage coefficients based on the difficulty of urban planning changes. Factoring in the difficulty of urban planning adjustments, we estimate the total commuting distance in major cities would be reduced to 83.7bn km per year.

10.2.2 Designing a Reasonable Housing System, and Matching Housing Supply with Demand to Reduce Carbon Emissions

China's housing supply is sufficient though the distribution of housing supply still has structural problems. China had around 30bn sqm in housing inventory in urban areas at end-2019, and the ratio between number of inventory housing and households (1.1/household) was already on par with that in overseas mature housing markets. However, structural problems remain to be solved: (1) Uneven geographical distribution. Judging by the permanent resident population, we believe the residential land supply is insufficient in ultra-high-tier and high-tier cities (classified by CICC real estate team). (2) Uneven distribution among different income groups. According to a survey by the National Bureau of Statistics (NBS), nearly 15% of urban households faced housing difficulties in 2015, and the proportion was over 25% in developed cities such as Beijing and Shanghai. Meanwhile, the lowest-income urban residents (20%) only occupied 6% of housing resources.

Housing construction is a major source of urban carbon emissions. We explore possible improvement of system design (from the perspective of housing supply, land market and taxation system) to address the housing supply–demand mismatch.

10.2.2.1 Housing Supply System: Focusing on Commercial and Government-Subsidized Housing

Government-subsidized housing programs satisfy the basic housing needs of mid/low-income households, helps build a multi-layer housing supply system, and reduce invalid housing supply. We believe the existing housing supply system can be improved in the following aspects:

- Catering to the housing needs of neglected groups. China's subsidized housing program has long neglected college graduates and professional employees. We believe maintaining a reasonable ratio between the supply of subsidized housing for professional employees and general subsidized housing (e.g. 7:3 in Shenzhen) can meet the basic housing needs of college graduates and professional employees.
- Designing a suitable investment and financing system to encourage governments and the private sector to participate in subsidized housing projects. The long investment recovery period and ineffective exit mechanism are major reasons hindering the acceleration of subsidized housing construction. We believe designing a suitable investment and financing system is the key to encouraging local governments and the private sector to participate in subsidized housing projects, such as increasingly land supply and using REITs (real estate investment trusts). At the same time, financial and fiscal measures could further encourage non-state-owned companies to participate in the construction of affordable housing, while expanding the coverage of policy-based housing should increase the return on REITs and enhance the feasibility of their exit mechanism.
- Balancing subsidized housing construction among different cities and districts. Land sales data over 2009–2019 suggests that more subsidized housing projects were built in medium/low-tier cities, and we believe supply of public rental housing in ultra-high and high-tier cities should be increased. Moreover, building subsidized housing and supporting infrastructure facilities where public transport is accessible should fulfill the demand from middle-to-low income households, and reduce the vacancy rate of subsidized housing. Meanwhile, extensive housing construction in one single region should be avoided to prevent social tension caused by residential isolation.

10.2.2.2 Deepening Land Market Reform

Land market reform is the prerequisite and foundation for building a multi-layered housing supply system. We believe that most supply-side issues in domestic real estate market can be traced back to the low efficiency of land supply. Under the existing institutional framework, we believe the land market reform should be deepened in the following aspects:

- Improving national system for the trading of construction land quotas. Academic studies generally accept that the inefficiency of national construction land quota system is the key reason for the uneven distribution of land supply. Provincial land quota trading systems are relatively mature, and cross-province trading of unused land quotas has been successfully trialed. We believe the national land quota trading system should be improved in the following aspects: (1) delegating of trading rights from provinces to counties and cities; (2) supplementing inner-provincial trading rights with inter-provincial trading; and (3) making information more transparent and distributing benefits fairly.
- Building unified construction land markets for urban and rural areas. In order to develop a unified land supply market for urban and rural areas, we believe: (1) construction land in all area should be equally considered in urban planning; (2) a unified benchmark land price system should be built and land transaction prices should be disclosed (market competition will drive land prices in rural and urban areas towards a similar outcome); and (3) a reasonable profit distribution system should be built to avoid assigning too much social responsibilities on collective land owners.

10.2.2.3 Fiscal and Taxation Systems: Introducing Fair and Reasonable Property Taxes

We believe the introduction of a fair and reasonable housing property tax will: (1) better motivate local governments to advance land market reform; and (2) curb speculative housing investment and facilitate income redistribution. We believe that the housing property tax should take these two issues into consideration:

- Clarifying the purpose of levying housing property tax. We believe property tax should remain stable over the long term, which differs from the flexibility and timeliness of regulatory measures. Judging by the experience in overseas housing markets, we do not believe that property taxes alone can sufficiently curb housing price hikes and speculation. On the contrary, the property tax is a stable fiscal revenue source (over 20% in developed countries) due to its stability, transparency, and counter-cyclicality. Overall, we believe a combination of property tax and vacancy tax (as charged in France and Canada) will propel home owners to sell or rent, and curb housing speculation.
- Implementing property tax in two steps; promoting supporting systems. Both the land transfer fee and property tax are related to home ownership, and this may

result in duplicate charges. However, we think the legal basis of property tax can be established by replacing lease renewal with sustainable land use after the period of residential land use expires, and adopting a low-rate and narrow-base property tax before the use period expires. We believe these measures would ensure that fairness is maintained, common housing demand is protected, and wealth effect in property market is regulated.

- By comparing the demand matching model and the current extensive reconstruction model, we estimate that the demand matching model will reduce the construction area by 21.2bn sqm in the next 40 years.
- Estimated new construction area in next 40 years under current "extensive demolition and reconstruction" model: Urban population is calculated based on population forecasts from the United Nations and the assumption that the China achieves its urbanization goal of 80% in 2050. New construction area per urban resident is calculated based on the correlation between urbanization rate and per capita new construction area. By multiplying the urban population and new construction area per urban resident, we estimate total new construction area in urban area at 65.1bn sqm over 2021–2060 (Fig. 10.3).
- Estimated new construction area in the next 40 years under the "supply–demand matching" model: We calculate reasonable demand for residential area in the next 40 years based on our estimate on the reasonable demand for houses over the medium-to-long term, and the assumption that per capita residential area will increase. We assume housing projects account for nearly 72% of total new construction area, which estimates total new construction area in urban area at 43.9bn sqm over 2021–2060.

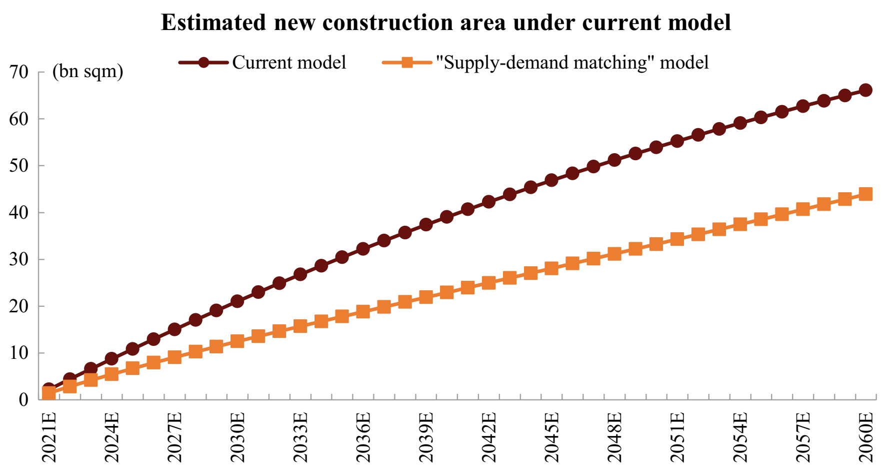


Fig. 10.3 Estimated new construction area under current "extensive demolition and reconstruction" model, and under "supply-demand matching" model. *Source* United Nations, National Bureau of Statistics, CICC Research

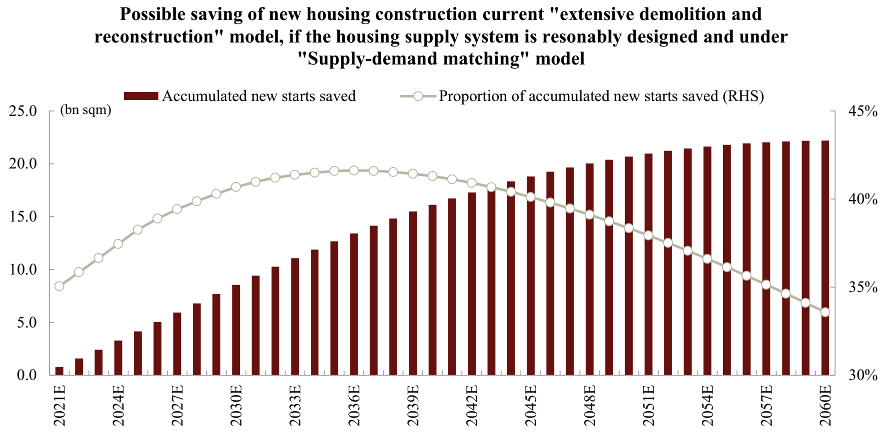


Fig. 10.4 Possible saving of new housing construction if the housing supply system is reasonably designed. *Source* United Nations, National Bureau of Statistics, CICC Research

- The difference of new construction area under two housing supply models is a redeeming feature of new housing construction. If China switches from current "extensive demolition and reconstruction" model to "supply-demand matching" model, we estimate new construction area in urban areas will drop 21.2bn sqm by 2060, equivalent to 33% of total new starts under the current model (Fig. 10.4).

10.2.3 Using Land Efficiently to promote High-Quality Growth

Low-efficiency and low-quality land use has led to high carbon emissions in cities. Under the conventional resource-driven development model, cities mainly rely on the input of production factors to enhance economic output. Most municipal governments have extensively developed land to attract rural migrants during the progress of urbanization, and the construction of large volumes of low-utilization supporting facilities pushed up overall carbon emissions. Average economic density in built-up areas of prefecture-level cities was around Rmb1,200/sqm by the end-2019, and there is plenty of room for improvement in all regions except for major city clusters in eastern China. We believe that improving city-industry integration and urban resilience is important for improving land use efficiency and reducing carbon emissions.

10.2.3.1 Improving City-Industry Integration; Exploring Development Axes

Regional centers and satellite cities within major city clusters in mid-west China are the main destination for the migration of people and industries from the more economically-developed eastern coastal regions. Such cities are focused on turning a large population into a driver of economic growth by using land more efficiently. The following two issues should be addressed:

- City-industry integration. We believe high-quality urban expansion can be achieved by setting up economic and technological development zones and high-tech industrial parks on the fringes of main urban areas and attracting high-quality industrial projects with tax reductions and exemptions as well as low land costs. For example, the Zhengzhou municipal government built a modern service industry system in the Zhengdong New Area by introducing industry leading, competitive and large-size companies, creating a new growth driver for Zhengzhou's economy. We believe building infrastructure and developing service industries are important for new districts to reduce the reliance on urban centers.
- Development axis: Central urban areas—urban fringes—new urban areas—cross-border functional areas. Major cities such as Zhengzhou and Chengdu all have developed central urban areas and new urban areas, but the economic density still needs to improve in regions located between the main and new urban areas and in regions within the one-hour urban living circle. Economic links between different areas should also be strengthened. The function of urban fringes depends on the degree of separation between residential and workplaces in central urban areas. Fringe areas will mainly be used as residential areas when there is a lack in central urban housing. Otherwise, urban fringes will be used to develop employment subcenters to enhance economic density in between the central and new urban areas.

10.2.3.2 Voluntarily Downsizing to Strengthen Urban Resilience

Population density declined in nearly 80 cities in mid-western and northeastern China over 2010–2019, and population migration and relocation of companies to other regions were major reasons. As inefficient land use in these shrinking cities may cause more serious consequences, we believe the following measures should be taken:

- Promoting industrial transformation. In response to the stagnation of local traditional industries, we believe governments should develop new industries to meet local conditions. For example, the Yumen municipal government switched development focus from oil resources to tourism and organic agriculture after local oilfields were exhausted.
- Strengthening urban resilience. Urban functions in sparsely populated cities should be restored by building ecological networks on idle land, and public

service facilities in city centers or commercial districts. This will strengthen urban resilience of these cities and prevent further population declines.

- Adopting proactive downsizing strategy. The bulk of domestic cities have yet to see serious downsizing, but we believe that cities should be forward-looking when urban planning. In cities that rely on traditional industries and lack natural resources, supply of land for traditional industries should be reduced, and inefficiently-used land in built-up areas should be readjusted.

10.3 Urban Transportation: Wider Use of AFVs to Reduce Carbon Emissions from Urban Transportation

This section discusses the potential reduction of carbon emissions in the urban transportation sector via measures such as increasing the use of alternative-fuel vehicles (AFV) in public transport, optimizing the urban railways, improving bike-sharing systems, and shortening average commutes. We believe that all buses, taxis and ride-hailing vehicles will be electric by 2030, and that more passengers may choose low-carbon modes of transportation such as urban rail transit and bike sharing.

Transportation methods in cities mainly include rail transit, buses, taxis, ride-hailing services, and bike sharing. Total urban passenger volume in China reached 165.6bn in 2019, of which buses, taxis, urban rail transit, ride-hailing platforms, and bike sharing accounted for 21%, 42%, 14%, 12%, and 10%, respectively. The proportion of taxis and buses declined compared to 2010, while the proportion of urban rail transit, ride-hailing platforms, and bike sharing increased 9%, 12% and 10%, respectively, contributing to the progress of building low-carbon transportation system.

Taxis, buses, and ride-hailing services are the main sources of carbon emissions from urban transportation (excl. ride-hailing as it is classed among passenger vehicles in Chap. 8). We estimate carbon emissions in China from taxis and buses in 2019 totaled 31.32mnt, with 24% from buses and 76% from taxis. We expect urban passenger volume to maintain annualized growth rate of 3–4% (daily passenger volume in the US grew at a CAGR of 3.0% as per capita GDP increased from US$13,000 to US$36,000). We do not believe that carbon neutrality for urban transportation has only one solution as we think it can be achieved via the following measures: (1) gradually increasing the use of electric buses, electric taxis, and electric vehicles for ride-hailing services; (2) promoting low-carbon transportation such as urban rail transit and bike sharing before the electrification of public transport is complete. The urban rail transit and bike-sharing segments are facing different issues, which will be discussed in the following sections.

10.3.1 Electrification of Urban Buses, Taxis, and Ride-Hailing Vehicles to Complete in 2030

The Innovation Center for Energy and Transportation (ICET) proposes in its report of *Research on the Timetable for the Exit of Gasoline-fueled Vehicles in China* (the "timetable research report") that taxis, ride-hailing cars, and buses should be among the first to complete electrification (gradual expansion from ultra-large cities such as Beijing, Shanghai and Shenzhen to other cities such as Tianjin, Hangzhou and Guangzhou).

- 59% of buses were electric in 2019, and the proportion may reach 100% in 2025. Data from the Ministry of Communications shows that China had nearly 0.41mn electric buses in 2019, accounting for 59% of total buses in the country, and 90% of buses sold in 2018 were electric. We expect the electrification of buses to reach 100% in 2025.
- Electrification of taxis and ride-hailing cars will be completed before 2030. According to the *Study on China's Timetable for Phasing-out Traditional ICE-vehicles*, gasoline-fueled taxis and gasoline-fueled cars for ride-hailing services will be gradually replaced by electric vehicles over 2020–2030.

Led by the government, taxis and ride-hailing cars may be first to achieve electrification. For example, the Shenzhen municipal government issued a blue-sky sustainable action plan in April 2018, and the electrification rate had reached 99% for taxis and 100% for buses as of 2019. The electrification of government cars, public vehicles, and buses can be achieved by governments restricting purchases of gasoline-powered vehicles. We expect the electrification of urban buses, taxis, and ride-hailing vehicles to complete in 2030, realizing zero carbon emission.

10.3.2 Switching to Low-Carbon Modes of Transportation Before 2030

We expect increased use of low-carbon transportation modes such as urban rail transit, bike sharing, and walking before 2030, mainly considering: (1) urban rail transit will transport more passengers as the model of financing and profitability matures; (2) governments will collaborate with enterprises to enhance the efficiency of bike-sharing services; and (3) residents will likely be able to walk and bike to their workplaces thanks to the shortened commuting distance.

10.3.2.1 Increased Use of Urban Rail Transit to Reduce Carbon Emissions from Urban Transportation

Density of urban rail transit in China remains lower than in developed countries. Among the world's ten largest cities measured by the operating mileage of urban rail transit, three are from China (Beijing, Shanghai and Guangzhou). However, the density of urban rail transit (as measured by the urban rail transit length per unit area) remains significantly lower in Beijing, Shanghai and Guangzhou (0.13, 0.07 and 0.05 km per sq.km.) than in overseas large cities such as Paris, New York and London (2.03, 0.54 and 0.29 km per sq.km.).

Urban rail transit volumes as share of total public transport still has a large room to grow. Even in large cities where urban rail transit was introduced years ago, such as Beijing, Shanghai and Guangzhou, the proportion of urban rail transit in total public transport volume is a mere 40%–50%, significantly lower than 70%–80% in Paris and Tokyo. Nationwide, the ratio is only 14%, indicating large upside. We expect urban rail transit transport volumes to maintain a 15% growth over the next 10 years, and its proportion of total public transport volume to reach 30%.

Urban rail transit companies are generally loss-making in China, and their earnings model needs further improvement. Data from China Association of Metros shows that average operating cost and operating revenue of urban rail transit per unit passenger-kilometers (PKM) stood at Rmb0.7 and Rmb0.5 in 2019, with average operating revenue to cost ratio falling from 78.0% in 2018 to 72.7%. Overall, operation of urban rail transit is loss-making, and metro as a major type of urban rail transit is also reporting losses due to inefficiency of business diversification and operating mechanism.

China may look to the experience of Mass Transit Railway's (MTR) in Hong Kong for ways to optimize its subway operation mechanism. The overall intensity of MTR passenger transport (as measured by daily transport volume divided by operating length) is close to 23,000 passengers per km per day, 30% higher than the passenger transport intensity of metro in Guangzhou and more than three times the national average (7,000 passenger per km per day). MTR Corporation adopts the transit-oriented development (TOD) model, under which property developers obtain the land development rights at a relatively low cost, and the property projects create a new revenue source. In 2019, MTR Corporation recorded EBITDA of HK$21bn (Fig. 10.5), with EBITDA margin reaching 38% (well above the 19% at domestic peer Shentong Metro) where the station commercial services, property development, rental and management businesses each contributed 29%, 27% and 20% of EBITDA. We think the Transit Oriented Development model (combination of metro and related property) will significantly enhance the operating efficiency of urban rail transit systems and reduce urban rail transit companies' reliance on government subsidies, creating a win–win for governments, the public, property developers as well as transit operators.

Issuance of real estate investment trusts (REITs) backed by urban rail transit assets offers a new solution for direct financing. We believe that REITs will serve as an effective supplement to the PPP model, and will help build a sustainable financing

Fig. 10.5 Breakdown of MTR Corporation's EBITDA in 2019 (unit: HK$100mn). *Source* MTR's announcement, CICC Research

system for urban rail transit. In addition, strict regulatory approval and information transparency are required to issue REITs in the urban rail transit industry. We believe closer supervision by regulators, the market and the public will force urban rail transit companies to improve operating efficiency, and diversify their business portfolio, thus improving sector profitability.

10.3.2.2 Bike Sharing: A Solution for Last-Mile Travel

As an environmentally friendly way of traveling, bike sharing could be a solution for the last mile from home and it would help reduce the traffic congestion and air pollution. The number of bike-sharing app users increased from 2.45mn in 2015 to 240mn in 2018, a CAGR as high as 358%, while fundraising volume in the bike-sharing industry climbed from Rmb5.2bn in 2015 to Rmb83.3bn in 2017. With the bike-sharing industry being reshaped in 2018, investors became more prudent, and aggressive marketing campaigns were replaced by efficiency enhancement and quality improvement as the new focus for bike-sharing companies. The competitive landscape largely stabilized in 2019, with the three internet giant-backed bike-sharing firms (Hellobike, Meituan and Qingju) holding a combined market share of 95%. We believe governments and bike-sharing companies should cooperate in addressing problems arising from the disorderly competition in past few years, such as excessive supply and unequal distribution of shared bikes, inefficient parking management, and hiding shared bikes for personal use.

We believe that governments should work more closely with bike-sharing companies to encourage shared bike supply, bike parking management, and business operation, in order to enhance the efficiency of bike-sharing services. Efficient management of shared bikes relies on the use of big data and the internet, and we thus believe governments and bike-sharing companies should collaborate in following aspects: (1) introducing a tender system for the increased supply of shared bikes; (2) jointly building the IT platform for data sharing; and (3) developing a credit system for the bike parking management. We believe closer cooperation between governments and bike-sharing companies will efficiently increase the active use of shared bikes, and reduce the vacancy rate.

10.3.2.3 Jobs-Housing Balance Should Shorten Average Commuting Distance and Reduce Carbon Emissions

Jobs-housing balance should markedly shorten commuting distance. As stated above, we estimate the total urban commuting distance will drop 83.7bn km per year if residence and workplace are evenly distributed in 36 major cities. On the basis of this calculation, we estimate carbon emissions from commuting will decrease accordingly by 2.92mnt after considering the energy consumption and carbon emissions of different modes of transport (Table 10.1).

10.4 Urban Construction: New Ideas, New Materials, and New Technologies Drive Reduction in Carbon Emissions

This section discusses: (1) volume of carbon emissions from urban construction; (2) previous policies aimed at promoting energy conservation and emission reduction in the building sector; (3) possible reduction of carbon emissions from building sector by 2060.

10.4.1 Overview: Building Sector as a Whole Accounted for 36% of National Carbon Emissions

10.4.1.1 Domestic Carbon Emissions from Building Sector Around 4.5bnt in 2019; to Drop 77% to 1.1bnt in 2060

Domestic carbon emissions from the building sector stood at around 4.5 bnt in 2019, and pace of emission growth significantly slowed during the 13th five-year plan (FYP) period (2016–2020). Based on data from China Association of Building Energy Efficiency (CABEE), we estimate domestic carbon emissions from the entire building process reached 4.3bnt in 2018 and 4.52bnt in 2019, much higher than the global level. The carbon emission from urban construction also outpaced the population over

Table 10.1 Estimated carbon emission reduction after residence and workplace are evenly distributed in 36 major cities

Estimates of carbon emission saved by commuting distance		
Saved commuting distance (bn km)	83.7	
	Proportion of passenger transportation volume	Saved commuting distance (bn km)
Buses	47%	39.0
Urban rail transit	16%	13.5
Passenger cars (including taxis and ride-hailing cars)	37%	31.2
Buses		Total CO_2 reduction: 2.92mnt
Bus electrification rate	59%	
Fuel consumption per 100 km of diesel buses (L)	30	
Assumption of the number of people carried by the bus	20	
Save carbon dioxide emissions by buses (thousand tonnes)	**520**	
Passenger cars		
Passenger car electrification rate	3%	
Passenger car fuel consumption per 100 km (L)	6.8	
Assumption of the number of passengers carried by passenger car	2	
Save carbon emissions by passenger cars (thousand tonnes)	**2,404**	

Source CICC Research

2008–2018 (76% vs. 5%) due to the large-scale urban construction. Domestic carbon emissions from building sector during the 11th, 12th and 13th FYP grew at a CAGR of 7.5%, 7.0% and 1.9%, respectively. The marked slowdown of carbon emission growth during the 13th FYP indicates the effectiveness of energy conservation and emission reduction policies introduced during the period.

We expect carbon emissions from building sector to drop 32% and 77% in 2030 and 2060 compared with 2019. Energy consumption and carbon emissions of building sector mainly come from material production, building construction and building management (Table 10.2). Given that the building sector is a major source of carbon emissions, we believe energy conservation and emission reduction in the building sector is important for China and the rest of the world to achieve peak carbon emissions and carbon neutrality. The IEA estimates global carbon emissions from building sector should annually drop 6% over 2020–2030 in order for the sector to achieve

Table 10.2 Carbon emissions from building material production, construction, and building management

<table>
<tr><th></th><th>Carbon emissions from material production</th><th>Carbon emissions from building construction</th><th>Carbon emissions from building management</th></tr>
<tr><td>Proportion of energy consumption (2018)</td><td>51%</td><td>2%</td><td>47%</td></tr>
<tr><td>Proportion of carbon emissions (2018)</td><td>55%</td><td>2%</td><td>43%</td></tr>
<tr><td rowspan="6">Measures to save energy and reduce emissions</td><td>Reduce emissions from building material production by: upgrading production technology, etc.</td><td>Reduce building construction by: optimize urban planning; prolonging building service life, etc.</td><td>Promoting advanced energy-conservation buildings: such as passive housing</td></tr>
<tr><td rowspan="5">Increase use of eco-friendly materials: such as light partition wall material, etc.</td><td rowspan="5">Enhance construction efficiency by: applying digital technology to building construction; enhancing the electrification of construction machinery, etc.</td><td>Design: to enhance the building energy efficiency</td></tr>
<tr><td>Building materials: promote use of green materials</td></tr>
<tr><td>Building management: Deploying smart energy conservation system</td></tr>
<tr><td>Energy equipment and energy supply system: Optimize forms of energy supply to enhance energy efficiency</td></tr>
<tr><td>Renewable energy: increase use of renewable energy sources such as solar power and geothermal power</td></tr>
</table>

Source China Association of Building Energy Efficiency, CICC Research

carbon neutrality in 2050. We expect carbon emissions from building sector to drop 32% and 77% compared with 2019 in 2030 and 2060 to 3.11bnt and 1.05bnt.

- Carbon emissions from building material production can be reduced by upgrading production technology, and the increased use of eco-friendly materials such as light partition wall materials.

- Carbon emissions from construction can be reduced by prolonging building service life, applying digital technology (improving construction efficiency and reduce the production of construction waste), and enhancing the electrification of construction machinery.
- Carbon emissions from building management can be reduced by promoting advanced energy-conservation buildings such as passive houses, and developing full-process energy conservation solutions.

10.4.2 Carbon Emissions from Construction: Reducing Overall Construction Volume and Enhancing Construction Efficiency

10.4.2.1 Production of Building Materials and Construction Both Generate Carbon Emissions, With the Majority Generated by Building Material Production

Nearly 51% of carbon emissions from the building sector were generated by building material production and construction. Based on data from the China Association of Building Energy Efficiency, we estimate domestic carbon emissions from building material production and construction reached 2.09bnt and 100mnt in 2018, accounting for 49% and 2% of total emissions from the building sector.

- Carbon emissions from building material production: Cement, steel and aluminum are major materials used in construction, and production of these materials each accounted for 35%, 61%, and 3% of total carbon emissions from building material production in China.
- Carbon emissions from construction: Emissions are largely due to energy consumption by construction machinery (such as excavator and power crane), as well as resource waste caused by the ineffective architectural design and the construction of temporary offices on construction sites.

Ways to reduce carbon emissions: Direct emissions reduction, and enhancement of construction efficiency. We think the new construction can be reduced by more reasonable urban planning and extension of building service life. Building demolitions and reconstructions are extensive in China. We believe reasonable and scientific urban planning can avoid unnecessary new construction, and the building service life can be prolonged by building quality improvements. In addition, the increased use of eco-friendly building materials and construction technologies will decrease carbon emissions per unit GFA.

10.4.2.2 Direct Emission Reduction: Improved Urban Planning and Extension of Building Service Life

Optimizing urban planning to avoid unnecessary demolition and reconstruction. Demand-based urban planning can avoid unnecessary new construction and reduce carbon emissions from building demolition.

Improving building quality to prolong building service life. Short building service life will lead to more new construction per year. The average service life of buildings constructed in the early stage of urbanization is less than 50 years in China, suggesting significant upside compared to an average of 132 years in the UK and 74 years in the US.

Using recyclable building materials. Unlike existing buildings made by reinforced concrete, the steel structure buildings are more recyclable, flexible, earthquake-resistant, and produce less construction waste. In addition, the steel used in the steel structure buildings can be recycled after buildings are dismantled. We expect the penetration rate of steel structure buildings to rise from current around 10% to 60% in 2060.

10.4.2.3 Improving Construction Efficiency #1: Reducing Carbon Emissions from Building Material Production

Cement: Technological upgrades can reduce unit consumption of coal and electric power during cement production. Our estimate of CO_2 emissions from producing one tonne of cement was 0.59tonnes in 2019. Due to technological upgrades and increased the use of clean energy sources, it will likely drop to 0.57tonnes in 2025, 0.55tonnes in 2030, and 0.40tonnes in 2060.

Steel: Switch from blast furnace to electric arc furnace (EAF). Our estimate of CO_2 emissions from producing one tonne steel was 1.52tonnes in 2019 and it will likely drop to 1.33tonnes in 2025, 1.10tonnes in 2030, and 0.50tonnes in 2060.

Aluminum: Increased use of power generated from clean energy sources. Our estimate of CO_2 emissions from producing one tonne of aluminum was 7.37tonnes in 2019 and it will likely drop to 6.91tonnes in 2025, 5.80tonnes in 2030, and 1.76tonnes in 2060.

New materials: Replacement of bricks and tiles with light partition walls. We estimate the application of light partition walls will reduce carbon emissions per unit GFA by 53 kg.

10.4.2.4 Improving Construction Efficiency #2: Reducing Carbon Emissions from the Construction Process

Industrialized construction. Penetration rate of prefabricated buildings remained as low as 13.4% in 2019 and we expect it to increase gradually. This, coupled with economies of scale, should reduce energy consumption and carbon emissions of buildings.

Digital technologies such as building information modeling (BIM) to reduce extra carbon emissions and building waste caused by reconstruction. Reconstruction often occurs due to inefficient communication between building designers and construction companies. We believe digital technologies such as BIM can detect flaws in the engineering design before construction starts, and this will help reduce waste and carbon emissions caused by reconstruction.

Electrification of construction machinery such as excavators. Only a small portion of existing construction machinery in China is electric, and most are small or micro excavators used in small construction projects. The large-scale adoption of electric excavators is hindered by the insufficient energy storage (insufficient for excavators' high power draw) and the difficulty of setting up connection cables on construction sites. We believe advances in battery energy storage technology and the promotion of industrialized construction, which helps tidy up construction sites, may help increase the use of electric construction machinery.

10.4.3 Carbon Emission from Building Management: Passive House Technology and Comprehensive Energy Conservation Solutions to Reduce Carbon Emissions from Building Management

10.4.3.1 Passive Houses (Ultra-Low Energy Buildings): Improving Thermal Insulation of Buildings to Save Energy

Passive houses (ultra-low energy buildings): High-standard insulation to reduce energy consumption, especially in cold regions. Passive house is a standard for energy efficiency in a building and its requirement for high-level heat insulation and air impermeability can minimize heat loss and active fossil fuel consumption.[1] We believe it is a reasonable solution to saving energy consumption by buildings in cold regions.

Promoting ultra-low energy buildings started in China during the 13th FYP and we expect a pick-up in the adoption of such buildings in northern China. China introduced the advanced passive house technology from abroad a few decades ago and gradually adapted it to domestic conditions. The demonstrative passive house projects were launched during the 13th FYP.

[1] The definitionincluded in *European standards, technologies and practices for ultra-low energy buildings and passive buildings* announced by MoHURD in 2011.

10.4.3.2 Comprehensive Energy Conservation Solutions for the Entire Construction Process

We believe coordinated efforts are needed for China's building sector to achieve its carbon emissions reduction target in 2060, and possible solutions include: (1) reducing building energy consumption by optimizing architectural design, increasing the use of eco-friendly building materials, and installing smart building management systems; and (2) reducing per unit energy consumption by optimizing energy systems such as heating, cooling, household hot water supply, and heat for cooking as well as promoting the use of renewable energy sources such as solar power, geothermal power, and PV.

Architectural design: Introducing Passive House-alike standards to enhance energy savings. The Ministry of Housing and Urban–Rural Development (MoHURD) issued several standards for conserving energy in buildings in the past few years to promote the concept of Passive House. Only some requirements are mandatory and we think full adoption of energy conservation standards will enhance the building energy efficiency.

Building materials: Promoting use of green building materials such as energy-efficient glass, and thermal insulation materials. The CICC Building Materials team expects the introduction of higher standards for building energy efficiency will boost demand for energy-efficiency glass, heat insulation materials, and lightweight materials.

Building management: Deploying smart energy conservation system for more efficient operation of energy systems and equipment.

Energy equipment and energy supply system: Optimizing forms of energy supply to reduce waste and enhance energy efficiency. The heating and ventilation facilities inside a building consume energy and produce carbon emissions. Assuming demand for energy consumption in buildings remains unchanged, we believe carbon emissions per unit energy consumption can be reduced by replacing central heating with flexible heating and using heating appliances that are more efficient.

Renewable energy: Increasing the use of renewable energy sources such as solar power and geothermal power. Data from the MoHURD shows that the penetration rate of renewable energy among civic buildings exceeded 4% at end-2015, and will likely reach 6% in 2020.[2]

10.4.3.3 Carbon Emissions from Building Management to Drop 79% to 450mnt Over 2019–2060

We expect domestic carbon emissions from building management to reach 1.49bnt in 2030 and 450mnt in 2060, down 31% and 79% compared with 2019. We believe factors affecting carbon emissions from building management include population,

[2] A target set by the MoHURD in the 13th FYP for conserving energy in buildings issued in March 2017.

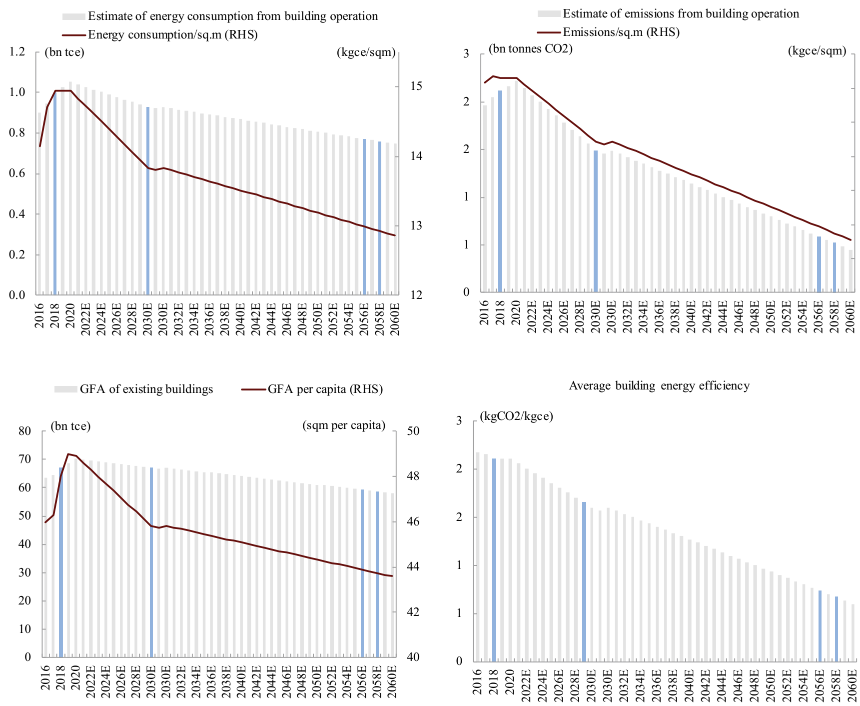


Fig. 10.6 Energy consumption and carbon emissions in domestic building sector will likely drop markedly in 2030 and 2060. *Source* National Bureau of Statistics, China Building Energy Consumption Research Report by China Association of Building Energy Efficiency, CICC Research

building GFA per capita, energy consumption per unit GFA (energy consumption intensity) and carbon emissions per unit energy consumption (energy efficiency). Specifically, we believe energy efficiency enhancement is a major driver of carbon emission reduction in building management (Fig. 10.6).

- Population: Slower growth from 2020 onwards. Data from National Bureau of Statistics shows that national population stood at 1.4bn in 2019. Based on data from United Nations, we expect population growth to gradually slow over 2020–2030, and total population start to decline from 2034 onwards. Based on our forecast, the national population will reach 1.46bn in 2030 and 1.33bn in 2060.
- Building GFA per capita: Expect continued declines from 2020 onwards. We estimate that domestic building GFA per capita is 49.0 sqm in 2019, including 15.7 sqm of public buildings, 36.8 sqm of urban residential housing, and 43.7 sqm of rural residential housing. We expect GFA per capita of public buildings, urban residential housing, and rural residential housing to drop to 13.3 sqm, 31.3 sqm and 36.8 sqm in 2060, respectively.

- Energy consumption intensity: We expect average energy consumption intensity to drop for building renovations, accompanied by a higher proportion of low-energy buildings. We estimate that national average building energy consumption reached 14.9 kgce/sqm in 2019 and it will likely decline to 12.0 kgce/sqm in 2060. We assume: (1) the proportion of near-zero ultra-low-energy buildings in existing building GFA will reach 3% in 2060; and (2) the energy conservation solutions along the value chain will help reduce energy consumption intensities of normal buildings. Based on these assumptions, we estimate average energy consumption intensity of buildings will drop to 12.9 kgce/sqm in 2060.
- Energy efficiency: We expect energy efficiency to markedly decline driven by lower proportion of non-fossil energy in primary energy consumption. Our estimate shows that national average building energy efficiency is 2.1 kg CO_2/kgce in 2019 and coal accounted for 76% of primary energy consumption (of which 50% was used for power generation, 30% for heat generation, and 20% as fossil fuels). In 2060, we expect national average building energy efficiency to drop to 0.6 kg CO_2/kgce, assuming: (1) the proportion of coal used for heat generation and as fossil fuels will fall to 5%; and (2) the proportion of fossil energy in primary energy consumption for power generation will drop to 10%.

10.5 Urban Maintenance: Reduce Energy Consumption by Public Service Facilities, and Improve Resource Recycling Efficiency

This section discusses potential reduction of carbon emissions from urban maintenance and the importance of improving the efficiency of urban maintenance and resource recycling. We believe energy conservation and adopting digital technologies are the key to reducing carbon emissions from public utilities such as water and heating supply. We also believe that introducing supportive policies will help reduce carbon emissions from facilities for water and heat supply and provide plenty growth potential for resource recycling.

With the economic development, the desire for a higher standard of living has driven up energy consumption for urban maintenance and operations. For example, the Building Energy Research Centre of Tsinghua University estimates that energy consumption for urban heating in northern China reached 212mnt of standard coal in 2018, producing around 550mnt of carbon emissions (around 25% of total emissions from the building sector). We believe improving urban maintenance efficiency and lowering unit energy consumption hold the key to reducing carbon emissions from urban maintenance. Carbon neutrality can be achieved through these two aspects.

- Improving urban maintenance efficiency. Public utilities such as heat and water supply are generally a necessity for urban residents, and the continued urban construction will gradually boost demand for such facilities. The lack of new

infrastructure facilities and the aging of existing facilities have led to low efficiency of urban maintenance. We believe energy use by urban infrastructure can be optimized by renovating existing infrastructure and improving supply efficiency.
- Improving resource recycling efficiency. The rapid urban development has substantially increased resource demand. We believe that the recycling of renewable resources is less energy-consuming than direct resource production which is aligns with the green city strategy. We see large upside in the domestic recycling rate.

10.5.1 Conserving Energy and Reducing Emissions by Using Technology to Reduce Carbon Emissions from Public Utilities

10.5.1.1 Water Supply: Using Digital Water Supply Management to Enhance Water Use Efficiency

Energy consumption for urban water supply: Water supply volume per resident has gradually increased in China, while stable urban water supply is of vital importance. Water supply companies need energy sources, mostly electrical power, to adjust hydraulic pressure and flow speed. Based on the current output of water supply firms in cities, our estimate shows that power consumption for urban water supply had reached 19.12bn kWh in 2019.

Possible measures to reduce carbon emissions from water supply: The low quality and inefficient management of water supply pipes built in the early stage of urban development have led to a water loss as high as 14% in 2019 according to MoHURD. We believe energy consumption for water supply can be reduced by using water more efficiently, raising awareness about water conservation among residents, and applying digital technology in water supply management.

- Reducing water loss: The National Water Pollution Control Action Plan stresses that renovating 50-year-old or older water supply pipes will improve the overall stability of water supply and reduce water loss. In addition, the digitalization of water management system can locate the water loss by monitoring water supply pipes, and eventually avoid water loss.
- Adopting smart water supply system: We believe technologies such as artificial intelligence, big data, and internet of things (IoT) will help water supply companies reduce unit power consumption.

10.5.1.2 Heat Supply: Promoting Central Heating to Improve Heating Efficiency in the Near Term; Transforming the Energy Mix over the Long Term

Central heating has been available in Northern China since the 1950s. The Qinling–Huaihe Line is a reference line used by geographers to distinguish between northern and southern China, corresponding roughly to the 33rd parallel. Central heating helps maintain the basic living condition for general public and the functioning of cities' utilities.

Promoting central heating has been faster in urban than in rural regions. Areas covered by central heating in cities and counties grew from 1.1bn sqm and 70mn sqm in the early 21st century to 9.25bn and 1.75bn sqm in 2019, a CAGR of 9% and 12%. According to the *China Clean Energy Development Report* (2020) by China Institute of Energy economics research, the central heating system covered 14.1bn sqm of northern cities and counties (78%) and 7bn sqm of northern rural regions (nearly 6%) as of 2019.

Central heating offers higher thermal efficiency than individual heating while coal remains a major heat source. According to *China Heat Supply Industry Development Report* (2020),[3] 45% of central heating in northern cities and counties came from coal-fired cogeneration, 27% from coal-fired boilers, 3% from gas-fired cogeneration, 10% from gas-fired boilers, and 7% from gas-fired wall-mounted heaters. Overall, coal and gas were the heat sources for nearly 72% and 20% of central heating. According to *Discussions on How to Improve Thermal Efficiency of Central Heating*, thermal efficiency is around 85% for cogeneration, 80%–90% for large heating boilers, 30%–50% for individual coal-fired boilers, 55%–65% for coal-fired boilers that complete energy conservation renovation, and 75%–80% for gas-fired boilers. We believe the central heating system can help reduce the energy consumption per unit heating area.

Carbon emissions in the heating supply sector are to be reduced by enhancing thermal efficiency in the near term and by transforming energy consumption mix in the long term. Household heating demand may continue to grow, thus, coordinated efforts along the value chain are needed in order to reduce carbon emission from urban heating. Cities can reduce emissions by: (1) reducing overall energy demand while satisfying residents' heating demand, via measures such as enhancing heating efficiency and adopting energy-saving building materials or smart building systems, and (2) improving the energy consumption mix by increasing the use of renewable energy.

[3] The report issued by China Urban Heating Association in August 2020.

10.5.1.3 Ample Downside in Carbon Emissions from Water and Heat Supply

Carbon neutrality and environmental protection will be long-term policy directions. 2021 marks the first year of the 14th FYP period, and we expect the government to continue promulgating policies that enhance water efficiency and promote clean heating.

- Water supply: The *National Water Pollution Control Action Plan* requires that water loss rate of national water supply pipes should fall below 10% in 2020. Given the renovation of old water pipes and the application of digital technology, we expect water loss will decline to 5% in 2030. In addition, we believe unit water consumption for both household and industrial uses will decrease on the construction of water-efficient cities. We expect unit water consumption to fall 5% in 2030 compared with 2020 and further decline in future. We think the digital technology will enhance the water supply efficiency and further reduce the unit energy consumption for water supply. We expect unit energy consumption for water supply will decline 5% over the 14th and 15th FYP periods.
- Heat supply: We expect the penetration rate of central heating to rise from 54% in 2020 to 75% in 2030 (including in rural regions) and the proportion of heat generated from coal burning to drop to 50%.

10.5.2 Resource Recycling to Help Build Low-Carbon Cities

10.5.2.1 Resource Recycling to Reduce Carbon Emissions

Domestic demand for resources keeps rising. The Chinese economy has maintained rapid growth since its opening-up which, coupled with industrialization and higher standards of living, has led to growing demand for resources. Chinese industrial added value increased at a CAGR of 10.8% since the start of the twenty-first century with the growth rate slowing from over 15% over 2000–2010 to 5.4% over 2011–2020. In addition, consumption per urban resident and per rural resident increased at a CAGR of 8.7% and 11.1% since the start-twenty-first century and maintained high growth on the whole despite mild declines in 2020 due to the pandemic.

Demand for all types of resources rising rapidly; resource recycling may help reduce urban carbon emissions. Rising gross industrial output and consumption levels boost China's resource demand. In 2019, China represented around 51%, 15%, and 40% of global consumption demand for steel, plastic and rubber. Since the production of industrial and consumer goods requires energy, we think the recycling of waste resources (i.e., steel, rubber and plastic) will ease the rising demand pressure and lower energy consumption in production, contributing to the goal of carbon neutrality.

- Scrap steel recycling: Overseas experience shows that the proportion of electric arc furnace (EAF) process in total output will rise when crude steel output reaches a

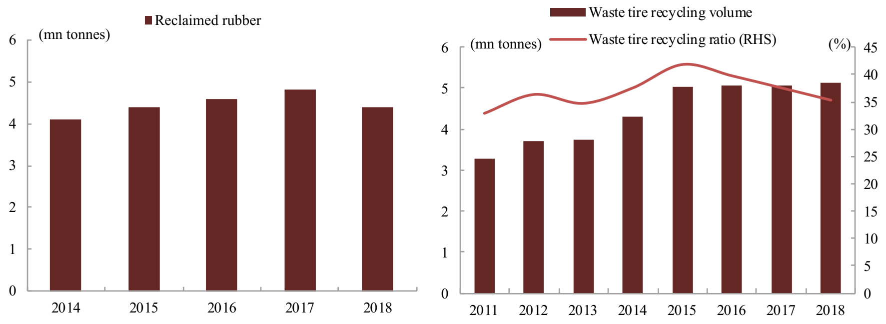


Fig. 10.7 Recycling volume of rubber and waste tires. *Source* Ministry of Commerce, China Rubber Industry Association, CICC Research

certain level. In 2018, EAF process only contributed 10% output, much lower than global market's 35%. According to the *Transformation and Upgrade Plan for the Iron and Steel Industry* released by the Ministry of Industry and Information Technology, China aims to raise the proportion of scrap steel in steelmaking to 30%, pointing to large growth potential. Compared with iron ore-based steelmaking, EAF process lowers energy consumption by 76%.

- Waste rubber recycling: Based on R&D data of relevant companies, we estimate that waste rubber recycling lowers renewable energy consumption by 30%. Recycling reduces waste rubber's harm to the environment. Data from China Rubber Industry Association shows that China produced 14.8mnt waste tires in 2019 with a CAGR of 5% over 2011–2019, pointing to ample waste tire resources. However, only 5.12mnt (35.3%) waste tires were recycled in 2018, far less than the 8.5mnt/year target for 2020 (set in the *Guideline for Green Manufacturing* 2016–2020) (Fig. 10.7).
- Plastic waste recycling: As a large plastic producer and consumer, China keeps improving its plastic recycling system. According to INTCO's prospectus, 38% of plastic waste was recycled in 2018. Data from Shanghai Resource Recycling Trade Association shows that China recycled around 30% plastic waste in 2019. According to a study published on the *Science of The Total Environment* by the University of Manchester, the recycling of one tonne of plastic lowers 2.3tonnes of carbon emission. The world is also stepping up efforts in plastic waste recycling. The EU plans to raise its plastic-waste recycling rate to 50% in 2025 and 55% by 2030. Japan aims at a 100% effective utilization of used plastic (including thermal recovery) in 2035. The US also announced its plan to achieve 100% recycling & reuse of plastic packaging in 2040.

Lithium-ion battery (LiB) recycling: Given efforts toward carbon neutrality, we believe alternative fuel vehicle will replace traditional vehicles and LiB demand will continue to surge, boosting demand for relevant raw materials (i.e., metals). Some elements will be reused in the new LiB production, lowering demand for the mining of raw materials and carbon emissions.

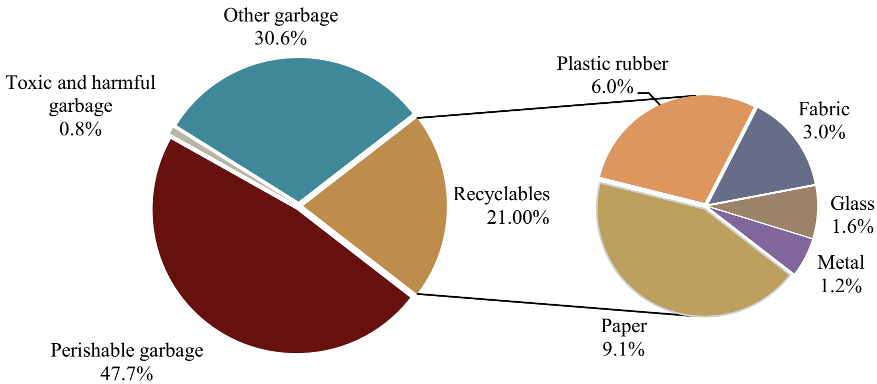


Fig. 10.8 Recyclable waste accounts for a high proportion in household waste. *Note* Data as of 2018. *Source* Data from Sound Group, CICC Research

10.5.2.2 Expecting Policy Support to Accelerate Recycling of Renewable Resources

Various recyclable materials are present in waste material. Households and industrial production produce considerable waste. China's waste volume is rising amid rapid economic growth. However, waste is not useless and contains a range of recyclable materials. Data from Sound Group shows that recyclable waste (i.e., paper, plastic, glass and scrap metal) accounted for around 20% of household waste in 2018 (Fig. 10.8).

Waste sorting lays a foundation for resource recycling. Waste sorting is the first step in resource recycling. We attribute the slow growth of renewable resource recycling in China to underdeveloped recycling systems, the extensive market expansion, and the country's reliance on low-efficiency waste pickers who collect renewable waste from the streets. We believe the construction of waste sorting system sets an industry-wide standard and will boost the recycling rate of renewable resources. The government has issued supporting policies such as "zero waste city" and "waste sorting" since 2019, promoting recycling and reuse of renewable resources.

Implementation of waste sorting policies. The Ministry of Housing and Urban–Rural Development and other eight ministries jointly announced the application of household waste sorting in prefecture- or higher-level cities on June 11, 2019. It stated that 46 major cities should complete the waste sorting and disposal system by the end of 2020 and other cities should complete the system in 2025. In November 2020, the Ministry of Housing and Urban–Rural Development and other 11 departments announced measures to promote household waste sorting, aiming to further reduce household waste volume, achieve harmless treatment, and turn waste into power. They plan to enact relevant laws and regulations and continue to raise China's household waste recycling rate to over 35% within five years.

Chapter 11
Digital Economy Goes Green: Taking Over Energy-Efficiency Management

Abstract Digital economy is one of the main themes of the 14th Five-Year Plan (2021–2025). The rapid development of new technologies—such as cloud computing, artificial intelligence (AI), and Internet of Things (IoT)—can support increased demand for cloud services and digital transformation at company and government department levels. These technologies can also boost the development of 5G base stations, data centers and the construction of other new technology infrastructures. The Fourth Plenary Session of the 19th CPC Central Committee in October 2019 has, for the first time, made it clear that data has become a new production factor in the era of the digital economy. We believe as the quantity and quality of the data both improve in the future, data can boost output growth in certain industries that are closely related to the digital economy and it can also provide computing power to support R&D of new technologies, serving as a source of technological innovation. New technologies represent a strong driving force for China's digital transformation, and electricity is also a key in supporting the development of the digital economy. We believe advanced technologies can fuel the growth of computing power, and stronger computing power, in turn, can help improve technologies and support sustained growth of digital economy. In our opinion, the process of digitization can also make the conversion of electricity into computing power be more energy efficient in the future, thereby reducing CO_2 emissions and boosting the growth of the digital economy. This chapter consists of four parts. In part one and two, we analyze how technologies help cities and industries improve energy efficiency and reduce CO_2 emissions. Then in the third section, we analyze how AI and other new technologies help the technology sector become more energy efficient and achieve carbon neutrality. In the final part, we summarize the challenges that are likely to be faced throughout the process of digitization.

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_11

11.1 Digitalization to Help Cities Improve Energy Efficiency and Reduce Carbon Emissions

In digital economy, we believe AI, 5G and other new technologies will empower multiple industries and enrich our lives. This prompts us to think about the following questions: How far are we from living in the digital lifestyles? And how can we achieve carbon neutrality in the digital lifestyles? We think smart cities that integrate digital technologies and utilize data into city governance and management will improve the way cities operate, thereby enhancing the experience of citizens in their daily lives.

The concept of “smart city” has drawn worldwide attention since it was proposed by IBM in 2008. In our opinion, smart city is more than just a concept but also represents the idea of incorporating digital technologies into city governance. We foresee that the utilization of new technologies such as AI, IoT, 5G networks, and cloud computing will transform the current society into a mature technology ecosystem that can make cities smarter and solve issues throughout the process of urbanization. A research organization Markets and Markets estimates that the total market size of the global smart cities’ development will increase from US$308bn in 2018 to US$717bn in 2023, implying a CAGR of 18.4%.

What are the application scenarios of smart city? As the idea of “smart city” is becoming increasingly popular and new smart city projects are under construction globally, we expect a new city governance model will be created and promote sustainable development of the entire society. Smart city projects have been carried out in many areas, including environmental protection projects such as pollution monitoring and waste sorting projects; transportation projects such as cooperative vehicle infrastructure systems (CVIS), smart parking lots, and smart transport planning; and projects in other sectors like smart factories for manufacturers, and big data-enabled city governance projects.

While smart city projects are able to make citizens’ lives easier and more enjoyable, digital technologies can also contribute to enhancing energy efficiency and reducing CO_2 emissions in cities. How will smart city projects in various application scenarios utilize technologies to cut energy consumption and reduce CO_2 emissions? And how much carbon emission reduction can this process ultimately achieve?

In order to answer these questions, we calculate the net reduction of CO_2 emissions enabled by CVIS, smart airports, and smart cargo transport, comparing the CO_2 discharged by facilities after utilizing digital technologies and the amount of emission reduction by these projects. In addition, we calculate the drop in CO_2 emissions per 1kWh of electricity to analyze the “value for money” provided by digital technologies.

11.1.1 CVIS Projects: Enhancing Vehicle Allocation Efficiency and Reducing Fuel Consumption

CVIS, enabled by sensor detection, edge computing, and autonomous driving technologies, can obtain and share information about road and vehicle conditions via roadside units and vehicle-mounted terminals. Such systems, based on traffic flow, accident and road condition forecasts, can enable the coordination between vehicles (and also between vehicles and infrastructure), thereby accelerating crossroad vehicle throughput, reducing vehicle fuel consumption, and increasing transportation safety and redundancy.

Efficiency enhancement: Smart traffic lights, tidal lanes, and autopilot cars can help reduce traffic congestion and make the traffic system safer and improve efficiency. Smart traffic lights can adjust light cycling time based on the amount of traffic to reduce the waiting time for both drivers and pedestrians. Tidal lanes allow cars to travel in a direction that can help improve traffic flow during rush hours by increasing the number of lanes for the side with heavier traffic. Autonomous vehicles, with vehicle-mounted cameras, radars, and other devices, can analyze conditions of vehicles and their surrounding environment before braking, taking turns, changing lanes, or adjusting their speed.

Emission reduction: Smart vehicles can utilize the simultaneous localization and mapping (SLAM) technology to locate their positions and formulate a map of their surroundings. This is achieved based on the information collected by vehicle-mounted cameras and the time-of-flight (ToF) distance measurement function of their laser radars. The SLAM technology helps vehicles improve route planning and reduce carbon footprint. In addition, trucks that use vehicle to everything (V2X) communication devices can travel in a fleet to mitigate wind resistance, share traffic light information to arrange braking time, and reduce fuel consumption thereby.

To what extent can autopilot enhance efficiency? According to a research from the University of Michigan, autopilot can reduce energy consumption by 19% compared with a traditional vehicle because they can improve route planning and optimize braking efficiency through the inter-vehicle-communication (IVC) system. In addition, we assume that the total number of private cars will drop by 1% following the wide adoption of autopilot technologies. Based on these assumptions, we estimate that by 2024, the annual carbon emission reduction of vehicles will be around 118mnt empowered by the autopilot technologies. Suppose that the amount of data generated by an autopilot test vehicle can reach around 10TB (terabytes) with an Inspur high-end full flash storage of HF18000G5 server. Then there would be about 25.66mn servers needed to support the computing process with 82mnt CO_2 emissions throughout the year. In total, we estimate that self-driving technologies can reduce CO_2 emissions by 42mnt per year, which means that the CO_2 emissions reduced by servers for self-driving cars is 1.51 kg/kWh (Table 11.1).

Table 11.1 Net reduction in CO_2 emissions from self-driving technologies per year by end 2024

Estimated energy conservation of autonomous driving vehicles:			
	Before the introduction of autopilot	Efficiency of energy conservation	After the introduction of autopilot
Number of cars per thousand people(unit)	500		
Population (bn)	1.42		
Car volumn (bn)	0.71	1%	0.7
Annual kilometers driven (km)	5,000	19%	4,050
Fuel consumption per hundred kilometers (litre)	7.5		7.5
Annual oil consumption (bn litre)	266.25	-20%	213.51
Corresponding reduction of carbon dioxide emissions (bn tonnes)			**0.12**
Estimated energy conservation of servers:			
Amount of data generated (TB/car/day)			10
Amount of annual data generated (bn TB)			2,566
Amount of data stored on a single server (TB)			100,000
Number of servers required (bn)			0.0257
Power of a single server (kW)			0.88
Amount of annual power consumed (bn kWh)			82
Corresponding carbon dioxide emissions (bn tonnes)			**0.08**
Conclusion			
Annual net reduction of carbon dioxide emissions (bn tonnes)			0.04
Reduction of carbon dioxide emissions per kilowatt-hour (kg)			1.51

Source Inspur website, CICC Research

11.1.2 *Smart Airport: Optimizing Aircraft Taxiing Distance with AI-Enabled Precision Calculation*

Through accurate prediction and management, Shenzhen Airport has reduced the taxi time of each aircraft by 1–2min, cutting oil consumption by 10–20L per aircraft on average. According to the Civil Aviation Administration of China (CAAC), there are around 10.25mn aircraft takeoffs and landings in China every year, and we estimate that smart airport projects will reduce carbon emissions by about 363,100tonnes per year (Table 11.2). Additionally, we estimate that data centers for smart airports will discharge 0.24mnt of CO_2 per year, based on the number of data centers and cabinets for the 241 airports in China as of February 18, 2021, and an additional 3% data storage required by AI- and digitization-enabled smart airports. Overall, we expect that smart airport projects can net reduce CO_2 emissions by 0.12mnt per year. This means the CO_2 emissions reduced by smart airport projects would be 1.52 kg/kWh.

11.1.3 *Smart Logistics: Internet Platform-Based Logistics Companies to Help Reduce the Empty Running Ratio*

We estimate that the current empty running ratio for cargo trucks in the logistics industry is around 40% in China. An internet platform-based logistics company operating under the model of technology companies such as Uber would notably reduce this ratio. According to the Ministry of Public Security, China had 29.44mn cargo trucks as of June 2020. We estimate that CO_2 discharged by trucks will fall by 69.5bn kg, if the empty running ratio drops to 20% (from 40%) and the empty mileage falls 147.2bn km per year. Assuming this logistics company requires 0.1mn data center cabinets, it would discharge about 8.5bn kg of extra CO_2 per year. Therefore, we estimate that internet platform-based logistics companies can reduce CO_2 emissions by 60.99bn kg per year in total or 8.14kg/kWh (Table 11.3).

11.2 Industrial Internet Empowers Enterprise Production to Achieve Cost Reduction and Efficiency Increase

Industrial internet projects are developing rapidly in China thanks to the wide deployment of 5G networks. As of March 2021, over 1,100 industrial internet projects were under construction in China. We note that the industrial internet has been applied in various scenarios by companies in multiple industries, such as Shanghai Commercial Aircraft Corporation of China, Shanxi Huayang Group, Sany Heavy Industry, and Xiamen Port. 5G technologies have facilitated industrial upgrades and transformation. The architecture of the industrial internet platform is displayed in Fig. 11.1.

Table 11.2 Net CO_2 emissions net reduced by smart airports

Estimated energy conservation of data centers:		
	Shenzhen Airport	Beijing Daxing Airport
Data center coverage areas (square meter)	4,232	16,000
Total building areas (square meter)	15,502	48,000
Cabinet areas as a percentage of total building areas	65%	65%
Cabinet areas (square meter)	10,076	31,200
Single cabinet areas (square meter)	2.5	2.5
Number of cabinets (unit)	4,030	12,480
Single cabinet power consumption (kW)	8	8
PUE	1.3	1.3
Launch rate	90%	90%
Load rate	70%	70%
Annual power consumption (kWh)	**231,331,342**	**716,296,090**
Annual power consumption of a single data center (kWh)	Number of data centers	Total energy consumption (kWh)
71,62,96,090	3	2,148,888,269
23,13,31,342	10	2,313,313,420
1,54,22,089	228	3,516,236,398
Total	**241**	**7,978,438,086**
Coefficient: Incremental proportional of introducing AI		3%
Total increase of power consumption (kWh)		**239,353,143**
Corresponding reduction of carbon dioxide emissions (tonne)		**238,635**
Estimated energy conservation of flight aircraft takeoffs and landings:		
Unit: thoudsand flights	2019 (No COVID-19 impact)	Average of 2019&2020 (With COVID-19 impact)
Eastern region	5,283	4,595
Central region	1,738	1,517
Western region	3,888	3,500
Northeastern region	746	640
Total	**11,655**	**10,252**
Reduction of fuel consumption (litre/flight)	15	

(continued)

Table 11.2 (continued)

Number of annual aircraft take-off and landing	102,516,818	
Amount of annual fuel consumption saved (litre)	1,537,753,273	
Corresponding reduction of carbon dioxide emissions (tonne)		**363,063**
Conclusion:		
Annual net reduction of carbon dioxide emissions (tonne)		**124,428**
Reduction of carbon dioxide emissions per kilowatt-hour (kg)		**1.52**

Source CAAC, CICC Research

Table 11.3 CO_2 emissions net reduced by smart cargo transport projects

Estimated energy conservation of cargos:		
Empty running ratio	40%	20%
Number of trucks (mn)	29.44	29.44
Mileage driven (km/year)	25,000	25,000
Annual valid mileages driven (bn km)	441.60	588.80
Annual invalid mileages driven (bn km)	294.40	147.20
Reduction of valid mileages driven (bn km)		147.20
Unit fuel consumption (litre/km)		20
Reduction of fuel emissions (bn liters)		29.44
Corresponding reduction of carbon dioxide emissions (bn kg)		**69.51**
Estimated carbon emissions of required data centers:		
Number of cabinets		100,000
Power consumption (kW)		7.50
PUE		1.30
Annual power consumption (bn kWh)		8.54
Corresponding carbon dioxide emissions (bn kg)		**8.52**
Conclusion:		
Annual net reduction of carbon dioxide emissions (bn kg)		**60.99**
Reduction of carbon dioxide emissions per kilowatt-hour (kg)		**8.14**

Note Valid mileage refers to situations where vehicles are fully loaded with cargo; invalid mileage refers to situations where vehicles are not fully loaded with cargo
Source Ministry of Public Security website, CICC Research

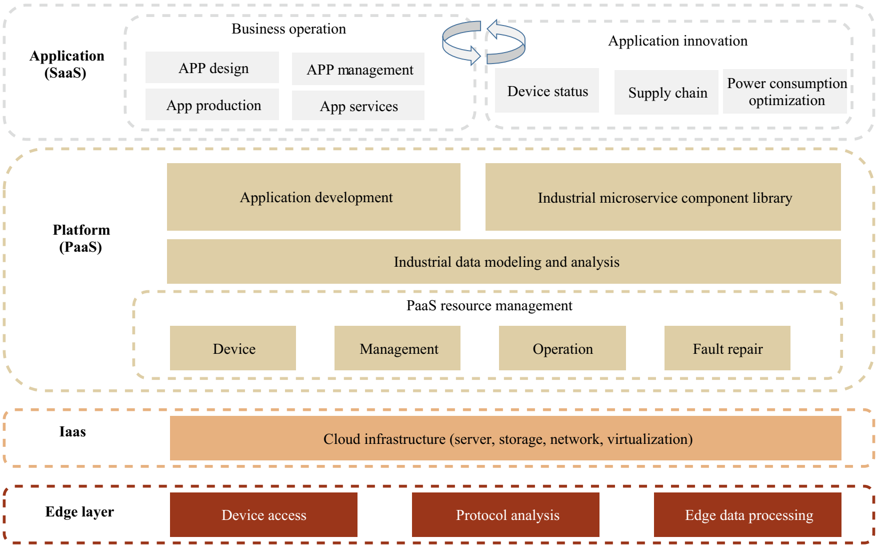


Fig. 11.1 Architecture of the industrial internet platform. *Source* Industrial internet platform whitepaper released by Alliance of Industrial Internet in 2017, CICC Research. *Note* SaaS refers to software as a service, PaaS refers to platform as a service, IaaS refers to infrastructure as a service

How will the industrial internet contribute to energy conservation and emission reduction? The industrial internet utilizes software platform and big data analysis technologies to process data collected by sensors in order to help industrial companies realize automatic control and smart corporate governance. Therefore, companies can use the industrial internet to improve manufacturing efficiency, reduce energy consumption and cut CO_2 emissions.

What are the implications of the industrial internet? According to the Ministry of Industry and Information Technology (MIIT), digital transformation of the economy is an inevitable trend. China should grasp the right development opportunities throughout the process of digitalization and informatization, given existing foundation and advantages to coordinate digital industrialization and industrial digitalization. In addition, China should also integrate a new generation of information technologies in manufacturing sectors, as well as mix manufacturing with other service industries and speed up the development of the digital economy. The ultimate goal of these fundamental pursuits is to promote the development of the real economy in China.

11.2.1 Industrial Internet: Enhancing Energy Efficiency Through Monitoring and Managing Energy Consumption Data

We are optimistic that the idea of carbon neutrality will promote the demand for downstream software applications, such as systems for energy monitoring, early warning, and other subdivisions. The increase in demand would bring business opportunities to downstream companies that provide digital solutions. For example, SaaS companies in energy management and control can help clients reduce energy consumption through analyzing energy consumption data collected via IoT and providing early warnings and solutions to clients. Companies that operate industrial cloud platforms can also help clients reduce cost and enhance efficiency, on the back of their cloud platforms and industrial apps.

State Grid released its carbon neutrality action plan in March 2021. According to the action plan, the firm will transform the power grid into an "energy internet" by strengthening the innovation and integration of technologies such as AI, IoT, big data, cloud computing and mobile internet technologies in the energy and power industry. This plan will also improve the interconnectivity of different energy sources and support alternative energy-based electricity and energy storage projects. State Grid also plans to accelerate the establishment of information collection, perception, processing, and application projects in order to promote data sharing on different energy sources and tap the value of these energy sources. According to the action plan, the firm aims to establish a world-leading "energy internet" by 2025.

- Smart energy management: Enesource Inc. provides industrial internet SaaS services to help clients reduce energy consumption and enhance efficiency. It has rolled out a series of solutions to improve energy efficiency in buildings, data centers, industrial companies, and commercial firms. Enesource can monitor energy efficiency online to help clients receive refined energy management services and reduce their CO_2 emissions. Specifically, it helps a national leading thermoelectricity company in Shanghai to develop smart energy services, reducing. Its energy costs by about Rmb15mn and cutting CO_2 emissions by around 44,200tonnes per year.
- Smart manufacturing: Cloudiip, a subsidiary of Boncloud (300166.SZ), is a leading industrial internet platform in China. Cloudiip supports multiple industrial application sub-platforms such as the big data platform for steel and iron companies, and the cloud service platform for boiler companies. At the same time, it has also launched a series of mobile apps to help industrial companies reduce energy consumption and improve manufacturing efficiency. For example, the big data platform for steel and iron companies can increase the value created by a blast furnace by Rmb24mn per year; the cloud platform for wind power companies can help reduce maintenance expenses by 30% per year; and the cloud platform for boilers can cut energy consumption by 15% per year.

11.2.2 Application of Big Data Technologies Brings Accurate Energy-Saving and Efficiency-Improving Solutions in Power and Water Sectors

The wide application of big data technologies makes it possible to process massive amounts of data. Big data platforms based on data analysis algorithms can visually monitor the data collected by sensors, make precision estimates, and improve the decision-making process. These platforms can help power and waterworks companies monitor data pertaining to electricity and water usage, thereby improving electricity and water management.

China Southern Power Grid has utilized big data technologies to provide electricity data services in Guangdong province. The company, via the electricity big data platform, can monitor electricity data at factories and identify high energy-consuming devices. For example, China Southern Power Grid has helped a manufacturing company identify the energy-intensive, fixed-frequency equipment in its factories and reduce energy consumption by 0.5mn kWh per year after installing frequency converters in these devices. China Southern Power Grid has also helped a group of companies reduce electricity consumption since 2019. According to China Southern Power Grid, electricity cost at its clients can drop 10–20% thanks to its electricity big data platform.

Xi'an Waterworks Company utilizes the smart waterworks platform to monitor information about water treatment and coordinate production and management and enhance the process of fault handling. This process enhances the timeliness of equipment maintenance, and improves planning, scheduling and decision making of the company. With this platform, the company can coordinate production data, videos, management, equipment, and employees. The smart platform has helped the firm reduce its labor cost by 3.6%, equipment breakdown ratio by 15%, suspension ratio by 20% and energy consumption by 20%.

11.3 AI and Other New Technologies Help the Technology Industry Reduce Energy Consumption and Enhance Energy Efficiency

In previous sections, we analyzed how technologies help reduce energy consumption and cut CO_2 emissions in different industries, and calculated the net reductions in CO_2 emissions facilitated by technologies. However, the technology industry itself is also energy intensive. In the following section, we analyze how AI and other new technologies have been utilized in the telecommunications industry to improve energy efficiency, and how 5G base stations and data centers have adopted multiple measures to reduce energy consumption.

11.3.1 How AI Technologies Help Companies Reduce CO_2 Emissions

The AI algorithm can be used in the operation, maintenance and management of internet data centers (IDC) to optimize their power usage. AI technologies have been utilized in equipment breakdown forecast and analysis, system fine-tuning, and internal services. Companies, via these technologies, can monitor the environment around data centers and then they can use a real-time cooling system to allocate resources and reduce energy consumption. Many companies—such as Google, Global Data Services (GDS), and Zhongxing Telecommunication Equipment (ZTE)—have already utilized AI technologies in their business operations.

- Google: In 2016, Google began to use the DeepMind AI system in its data centers. This system has reduced energy consumption by more effectively controlling their servers, cooling systems and other modules. Cooling expenses at Google data centers have dropped 40% since then.
- GDS: GDS is one of the first domestic companies to utilize AI technologies in their data centers. The development and design of its weak current system and software should ensure that AI technologies can be applied, so as to make AI algorithm-based temperature control possible. It has also utilized robots to patrol data centers and detect equipment breakdowns, thereby reducing equipment maintenance costs and improving early warning systems.
- ZTE: The firm has developed an AI algorithm system based on its own AI Explorer platform. This system can collect data about the cooling and electricity systems before conducting data governance on the AI-enabled platform. It also utilizes AI algorithms to improve the operation strategy, which can reduce energy consumption by 15%.

In the 5G era, AI technologies can improve the adaptability of base stations to reduce their energy consumption. AI-enabled smart energy efficiency solutions can help networks under different standards reduce energy consumption. The AI system can use historical data to build learning models, and continues modifying the models based on the real-time data. ZTE began providing AI-enabled energy efficiency solutions for domestic telecom carriers in 2019. This product has been utilized in more than 100,000 residential communities, helping base stations reduce energy consumption by 10%–15%. We estimate that electricity consumed by every 1,000 base stations can be reduced by 1.5–2mn kWh per year.

- Recognizing energy-saving scenarios: The AI system can automatically monitor the energy efficiency of base stations in different residential communities. It can be connected to the interfaces of base stations and the Oracle Management Cloud (OMC) platform. Base stations can be operated under the energy efficient model in accordance with changes to traffic volume and other business indicators.

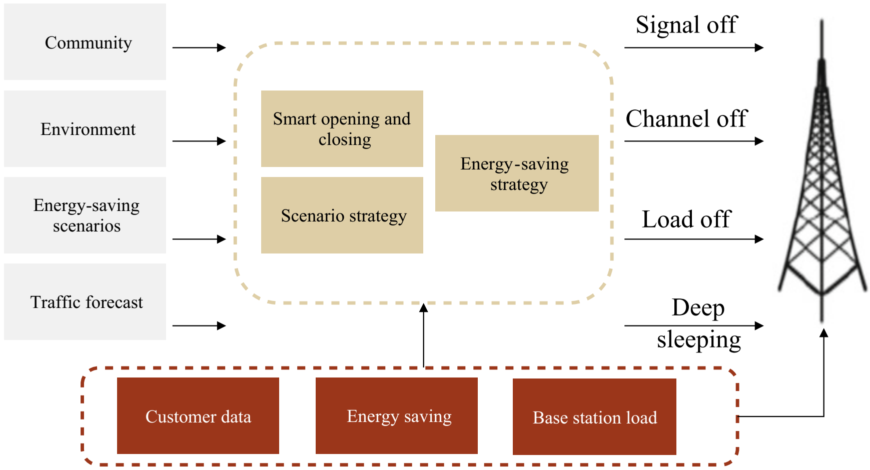


Fig. 11.2 AI-enabled energy efficiency strategies. *Source* Research on AI-enabled energy efficiency technologies for 5G stations published on Application of Electronic Technique in 2019, CICC Research

- Business forecast: The AI system can estimate the load of networks, based on AI algorithms, base station data, and the load model of the training business. With the load forecast, the system can take measures to regulate traffic volume and improve user experience.
- Choosing energy efficiency strategies: The system can improve learning algorithms to choose, fine-tune, upgrade, and execute proper energy efficiency strategies. Such efforts can also help companies achieve energy efficiency goals and KPI targets. The selection model of AI-enabled energy efficiency strategies is shown in Fig. 11.2.

11.3.2 Improving Equipment, Station Locations, and Networks to Help 5G Jointly Built and Shared Base Stations to Reduce Energy Consumption

Energy consumption of the telecommunication industry has been increasing in the 5G era. However, we think the total energy consumption in the construction of 5G networks will drop due to improved equipment and advanced technologies. According to China Communications Standards Association, no-load power consumption of main equipment in existing 5G base stations is around 2.2–2.3kW, and the full-load power consumption stands at around 3.7–3.9kW. We estimate that the average power consumption of 5G base stations will drop to around 3.3kW by 2025 (vs. 3.85kW in 2019), as equipment is likely to become more energy efficient and base stations will no longer operate under the full-load model thanks to the use of hibernation technology and other new technologies for the base station. In addition, we estimate that the overall power consumption of 5G base stations will be around 79.3bn kWh in 2025, as 2G and 3G networks will be gradually dismantled and the growth of new 5G base stations will be mild (Table 11.4).

11.3.3 Software and Hardware Technologies: The Trend of Upgrading Base Structures of Telecom Infrastructure

Base-station equipment: Enhancing energy efficiency of active antenna units (AAU) will notably reduce energy consumption. RF amplifiers are more energy intensive than other devices in base stations. As a result, we think improving technologies for key devices—such as power amplifier modules, digital intermediate frequency (DIF), baseband modules, and transmitter receivers—will noticeably improve the energy efficiency of AAU. For instance, we think the power consumption of base-station equipment will drop and the performance of 5G systems will improve, if companies can improve semiconductor technologies and upgrade semiconductors to make chips smarter and enhance their integration and processing capability.

Base-station locations: Using software and AI technologies to reduce energy consumption of base stations in residential communities. AI technologies can analyze traffic volume in different hours and in different locations, and then they can improve energy efficiency solutions for different base stations during different hours. Such solutions can help reduce energy consumption without weighing on user experience.

Networks: Multi-network coordination technologies can help existing networks achieve energy reduction targets. Given the use of 5G technologies, we think 4G networks using TDD/FDD technologies will coexist with 5G networks that utilize NR technologies. According to China Mobile Research Institute, multi-network coordination technologies can apply clustering and neutral network algorithms to improve the energy efficiency of 5G equipment. Such technologies can both be used in 4G and 5G networks. According to China Mobile Research Institute, companies have also developed the 4G multi-carrier energy system (MCES). Tests on existing networks show that the MCES can reduce the power consumption of 4G networks by more than 0.4mn kWh per 10,000 residential communities. We think the power consumption reduction will be even more notable, after base stations are connected to 5G networks. The plan for energy-saving technological advancements for 5G base stations is displayed in Fig. 11.3.

Table 11.4 Power consumption by base stations of three major telecom carriers in China

China Mobile	2018A	2019A	2020E	2021E	2022E	2023E	2024E	2025E
Number of 2G base stations (thousand)	802	802	802	321	240	80	–	–
Average Power (kw)	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*
Number of 3G base stations (thousand)	55.5	55.5	55.5	55.5	55.5	55.5	27.7	27.7
Average Power (kw)	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*
Number of 4G base stations (thousand)	2,410	3,090	3,150	3,180	3,200	3,210	3,210	3,210
Average Power (kw)	*1.04*	*1.04*	*1.04*	*1.04*	*1.04*	*1.04*	*1.04*	*1.04*
Number of 5G base stations (thousand)	–	60	410	750	1,050	1,350	1,650	1,950
Average Power (kw)	–	*3.85*	*3.85*	*3.85*	*3.66*	*3.48*	*3.30*	*3.30*
Total Power (kWh)	2,806,236	3,631,042	4,867,129	5,134,441	5,526,970	5,715,614	5,798,516	6,019,575
Average electricity price (RMB/kWh)	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Total electricity cost of base stations (RMB bn)	**18.24**	**23.60**	**31.64**	**33.37**	**35.93**	**37.15**	**37.69**	**39.13**
As a percentage of revenue (%)	2.48	3.16	4.21	4.30	4.47	4.58	4.61	4.72
China Telecom	**2018A**	**2019A**	**2020E**	**2021E**	**2022E**	**2023E**	**2024E**	**2025E**
Number of 2G base stations (thousand)	459	459	459	184	138	46	–	–
Average Power (kw)	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*
Number of 3G base stations (thousand)	31.8	31.8	32.0	31.8	31.8	31.8	15.9	15.9
Average Power (kw)	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*
Number of 4G base stations (thousand)	1,380	1,590	1,650	1,680	1,700	1,720	1,720	1,720
Average Power (kw)	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*
Number of 5G base stations (thousand)	–	40	215	405	585	765	945	1,125
Average Power (kw)	–	*3.85*	*3.85*	*3.85*	*3.66*	*3.48*	*3.30*	*3.30*

(continued)

Table 11.4 (continued)

China Mobile	2018A	2019A	2020E	2021E	2022E	2023E	2024E	2025E
Total power (kWh)	1,606,890	1,934,069	2,579,567	2,749,695	3,017,585	3,166,818	3,239,661	3,388,260
Average electricity price (RMB/kWh)	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Total electricity cost of base stations (RMB bn)	**10.44**	**12.57**	**16.77**	**17.87**	**19.61**	**20.58**	**21.06**	**22.02**
As a percentage of revenue (%)	2.77	3.35	4.37	4.49	4.72	4.75	4.69	4.74
China Unicom	**2018A**	**2019A**	**2020E**	**2021E**	**2022E**	**2023E**	**2024E**	**2025E**
Number of 2G base stations (thousand)	329	329	329	329	165	33	–	–
Average Power (kw)	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*
Number of 3G base stations (thousand)	22.8	22.8	23.0	22.8	22.8	22.8		
Average Power (kw)	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*
Number of 4G base stations (thousand)	990	1410	1500	1,550	1,580	1,600	1,600	1,600
Average Power (kw)	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*	*1.0*
Number of 5G base stations (thousand)	–	40	171.0	359.0	479	599	719	839
Average Power (kw)	–	*3.85*	*3.85*	*3.85*	*3.66*	*3.48*	*3.30*	*3.30*
Total Power (kWh)	1,152,769	1,672,134	2,196,597	2,589,135	2,646,076	2,662,181	2,658,508	2,724,325
Average electricity price (RMB/kWh)	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Total electricity cost of base stations (RMB bn)	**7.49**	**10.87**	**14.28**	**16.83**	**17.20**	**17.30**	**17.28**	**17.71**
As a percentage of revenue (%)	2.58	3.74	4.76	5.40	5.27	5.10	4.96	4.95
Sum of three telecom operators	**2018A**	**2019A**	**2020E**	**2021E**	**2022E**	**2023E**	**2024E**	**2025E**
Number of 2/3G base stations (thousand)	1,700	1,700	1,700	944	653	269	44	44
Number of 4G base stations (thousand)	4,780	6,090	6,300	6,410	6,480	6,530	6,530	6,530
Number of 5G base stations (thousand)	–	140.0	796.0	1,514.0	2,114.0	2,714.0	3,314.0	3,914.0

(continued)

Table 11.4 (continued)

China Mobile	2018A	2019A	2020E	2021E	2022E	2023E	2024E	2025E
Power consumption of 2/3G base stations (bn kW/h)	11.9	11.9	11.9	6.6	4.6	1.9	0.3	0.3
Power consumption of 4G base stations (bn kW/h)	43.7	55.7	57.7	58.7	59.3	59.8	59.8	59.8
Power consumption of 5G base stations (bn kW/h)	–	4.7	26.9	51.1	67.8	82.7	95.9	113.3
Total power consumption (bn kW/h)	**55.7**	**72.4**	**96.4**	**116.4**	**131.7**	**144.3**	**156.0**	**173.3**
2/3G base station electricity cost (bn kW/h)	7.7	7.7	7.7	4.3	3.0	1.2	0.2	0.2
4G base station electricity cost (bn kW/h)	28.4	36.2	37.5	38.1	38.5	38.8	38.8	38.8
5G base station electricity cost (bn kW/h)	0.0	3.1	17.5	33.2	44.1	53.7	62.3	73.6
Total electricity cost (RMB bn)	**36.18**	**0.47**	**0.63**	**0.76**	**0.86**	**0.94**	**1.01**	**1.13**
Proportion of 2/3G base station electricity cost (%)	*21*	*16*	*12*	*6*	*3*	*1*	*0*	*0*
Proportion of 4G base station electricity cost (%)	*79*	*77*	*60*	*50*	*45*	*41*	*38*	*34*
Proportion of 5G base station electricity cost (%)	*0*	*7*	*28*	*44*	*51*	*57*	*61*	*65*

Source Corporate filings, CICC Research

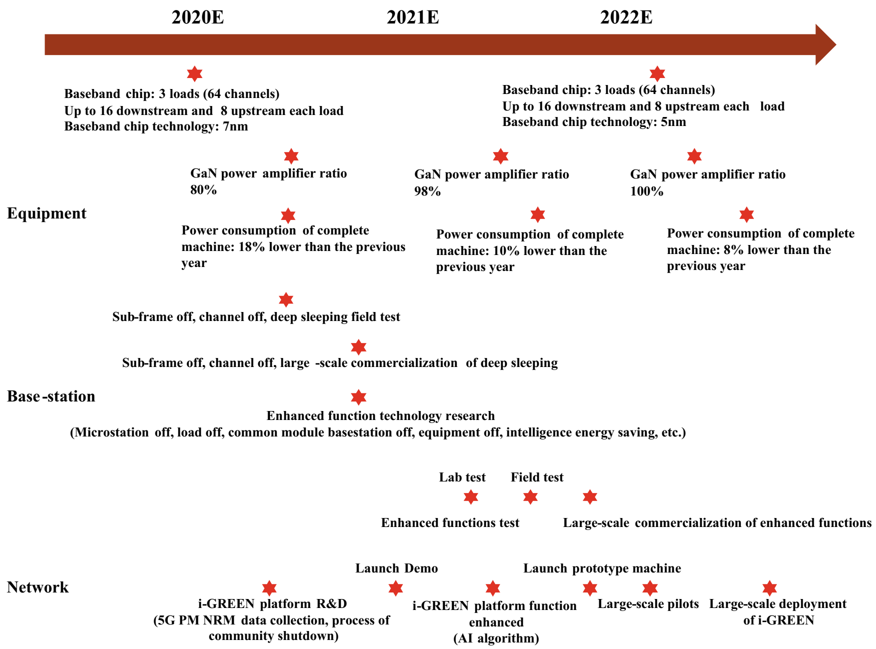


Fig. 11.3 Timeline of energy-saving technologies for 5G base stations. *Source* CMRI, CICC Research

11.3.4 Data Centers: Cloud Computing and Advanced Refrigeration Technologies Help Improve Power Usage Effectiveness (PUE)

Data center architectures have evolved from centralized computing in 2000 to distributed computing in the PC era and then back to centralized computing in the new era. In the 1960s, computing and storage resources were stored in mainframes, which served as the computing power supply centers for companies. Only business customers could afford these expensive devices. As a result, computing resources were concentrated in companies in the era of mainframes. In 1979, IBM launched private computers (PC) and started the PC era. Computing resources began to be operated separately, shifting from mainframes to PC. Since 2000, the computing model has become centralized again thanks to data centers that could operate more than 1,000 servers.

Data centers are the underlying infrastructure in the era of the digital economy; they play a crucial role in converting electricity into computing power. Large data centers implement centralized management of computing and storage resources (Fig. 11.4), and users can share resources through the internet. This model is

Fig. 11.4 Large data centers manage computing and storage resources. *Source* Juimg.com, CICC Research

becoming increasingly popular, and the concept of "cloud computing" is gradually developing (Fig. 11.5). Data centers represent the upstream of the IDC industry value chain. They provide server trusteeship and other infrastructure services for cloud companies, internet companies, and government customers. Data centers convert

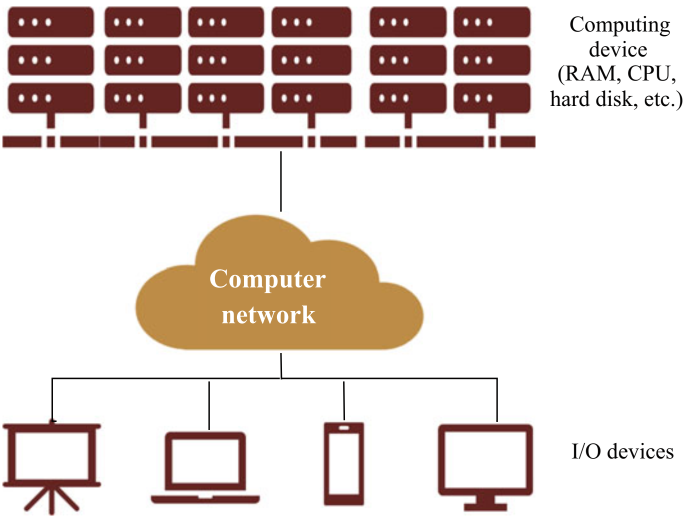


Fig. 11.5 Cloud computing concept diagram. *Source* Sangfor.com, CICC Research

electricity into computing power, as their machinery equipment and temperature & humidity control devices consume electricity.

Collective computing power can notably reduce energy consumption at data centers, contributing to the process of achieving carbon neutrality. According to Pike Research, the use of cloud computing technologies reduced the energy consumption of global data centers by 38% in 2020. AWS believes that collective computing resources can notably enhance computing efficiency. Microsoft estimates that Azure collective data centers are 72%–98% more energy efficient than traditional data centers, as they can enhance the IT maintenance efficiency, IT equipment efficiency, data-center infrastructure efficiency, and regeneration capacity.

Standard and modular electromechanical devices can help data centers reduce cost and enhance efficiency. We think the structure of the machine room system is the key to the competence of operating IDC. Arranging the structure of this system requires the capability to predict the IT load capacity, the electromechanical layout, and the heat-sinking conditions to support higher power density in the future.

Electricity and refrigeration resources represent the core electromechanical device services provided by IDC. IT and refrigeration devices account for around 85% energy consumption of IDC. The use of IDC cooling measures should follow local conditions. In northern China, devices can be cooled via indirect evaporation as the environment is drier and colder, thereby reducing the use of cooling water. In southern China, IDC utilize the immersive liquid cooling technology, using liquid to reduce the heat generated by central processing units (CPU), memories, and other IT devices. IDC also utilizes distributed energy supply, high-voltage direct current power supply, and modular UPS technologies to reduce power losses and improve PUE.

Sharing electromechanical resources and using modular base stations can also help reduce energy consumption and enhance efficiency. Prefabricated modular data centers represent a pre-engineered product. The infrastructure units in such data centers are pre-assembled in factories before being re-assembled at construction sites. Data centers that utilize the modular design can be constructed rapidly. They share cabinets and other infrastructure in order to save the space in machine rooms and reduce electricity cost. Modular data centers also enjoy policy tailwinds in China. The Three-Year Action Plan for Cloud Computing (2017–2019) released by the MIIT encouraged companies to improve technologies and products for environmentally friendly and modular data centers. For example, Chindata provides modular cooling devices and power distribution devices for data centers, thereby shortening the construction period of data centers by 30%–40%. US companies also use the modular design to make the allocation of machine room resources more flexible. As a result, a machine room can operate in conformity with standards for tier-2, tier-3, and tier-4 data centers, cabinets with different unit power dissipation can expand their capability, and companies can provide data centers for wholesale and retail customers. We think modular technologies can show companies' competence in utilizing IT equipment technologies. However, the iteration cycles for IT and network equipment technologies last shorter than that for infrastructure. We think modular data centers are key to improving the planning for the structure of machine rooms

Table 11.5 Advantages of modular data centers

No need to differentiate functions	No need to differentiate functions in advance as with traditional data centers. Modular data centers can effectively integrate the functions of the host room, the power engine room, and the AC engine room into the modules saving space for the computer room.
Prefabrication by the factory	The infrastructure needed for the prefabricated modular data center such as cabinets, ACs, UPS, networking, wiring, monitoring, etc. are all prefabricated by the factory. The factory assembly line ensures the quality of each process and improves the reliability of data centers.
Quick assembling through standardized installation	The prefabricated modules can be quickly assembled and aligned at the project site. The internal structure of the module follows the standardized installation, which helps simplify the construction work, lower the difficulty of the project, shorten the construction period, and reduce labor cost. Data centers that used to take one or two years to build can now be completed within one or two months.
Easy error checks	Prefabricated modular data centers can be built on demand, and capacity can be expanded as needed. Such flexibility allows phased investment in data centers and improves overall operational efficiency. Meanwhile, only the faulty module needs to be removed and repaired when an error occurs. It will not affect the entire system as with traditional data centers, where it will take a lot of time to identify the fault.
High density, low cost	Prefabricated modular data centers usually use horizontal AC between rows to cool nearby areas with stable air supply and temperature. Coordinated with the shutdown of cold/hot channels and strict air management, they can greatly improve the uitilization rate of AC in the computer to deliver cooling for 20kW or higher power density per cabinet. It also saves space in the room and electricity costs, reducing PUE.
One-stop professional services	The characteristics of the prefabricated modular data center enable one-stop services from manufacturers, and prevent buck-passing or a lack of clarified responsibilities. With advanced and user-friendly management software, staffs who manage the computer rooms can control the operating status of the entire data center at any time.

Source Delta Electronics, CICC Research

so as to make electromechanical modules more applicable and more affordable and enable such modules to work in conformity with standards for the rapidly-changing information and communication technologies. In our opinion, enhancing the efficiency of modular and standard equipment means that companies need to keep the entire structure in their mind. The detailed advantages of modular data centers are listed in Table 11.5.

11.4 What Are the Challenges Ahead?

There is a long way to go before reaching carbon neutrality. In our opinion, investors should be neither too optimistic nor too pessimistic. In order to realize the goal of net zero carbon emissions, it is necessary to be aware of potential risks and challenges ahead, and in particular we need keep an eye on the following challenges.

The penetration rate of the industrial internet remains relatively low. According to the Industrial Internet Industry and Economic Development Report (2020) released by China Academy of Information and Communications Technology (CAICT), the economic value-added scale of China's industrial internet industry reached Rmb3.1trn in 2020, accounting for 2.9% of the total GDP. The industrial internet has been gradually used in petrochemical, steel & iron, electronics, and information industries but the penetration rate is still only 2.76% and there is still much room for improvement. We think this industry should consider the following questions. How to utilize data to shorten the commercial investment period and extend the investment return period? How to improve the inclusiveness of their platforms and the connectivity of data in order to utilize data as a production factor to the utmost degree.

The application of energy-saving systems in many cases remains at the data collection level. The energy conservation platform enabled by the industrial internet technologies consists of three layers—the edge layer is for data collection, the platform layer is for the industrial PaaS (platform as a service), and the application layer is for industrial apps. We note that in real applications, some companies only use this system to collect data, and the data they collect has not been utilized to help reduce energy consumption. We believe that the industry in the future should think about how to quickly realize data empowerment to shorten the commercial investment cycle and generate returns over an extended period of time. How to achieve platform compatibility and data connection, and maximize data production factors?

The costs of developing and maintaining AI systems are generally high. For a wide range of small and medium-sized companies, it is necessary to balance the trade-off between the benefits of higher energy efficiency and the cost of AI systems. The use of AI systems to reduce energy consumption is facing headwinds from the increased cost of system development, data storage and algorithm updates, as the computing power of such systems continues to increase. Meanwhile, the huge energy consumption brought by the increase in computing power should also not be underestimated. Small and medium-sized companies should be aware of the trade-off between the use of AI systems to improve energy efficiency and the energy consumed by such systems. How to reduce the cost of developing and maintaining AI systems, how to help companies in different industries to develop and adopt AI systems, and how to use AI technologies to reduce energy consumption and cut CO_2 emissions are the questions we need to consider.

The feasibility of using 5G technologies to reduce energy consumption remains to be seen. China Mobile Research Institute (CMRI) expects that by 2022, the use of 5nm process baseband chips will be realized, the penetration of GaN power amplifiers will also reach 90% with the development of process, semiconductor material, and

RF system technologies. In the meanwhile, CMRI estimates that the overall power consumption will drop 8% YoY in 2022. In addition, through the sharing of baseband units (BBU) following the use of 5G networks will likely remove the need for hardware board configuration thereby reducing the power consumption. However, it remains to be seen whether using 5G technologies to reduce energy consumption will be effective since most of these developments are still developments. In addition to considering making technological breakthroughs, we suggest thinking about the following questions. How to improve the allocation of low-frequency resources in order to reduce construction of base stations? How to help telecom carriers, to the utmost extent, co-build and share base stations?

We see risks and challenges ahead in the journey towards carbon neutrality. We think companies and industries should be aware of these risks and challenges and stick to the ultimate goal of achieving carbon neutrality.

Chapter 12
Green Investment: New Trend, New Direction

Abstract This chapter focuses on asset and investment management within the framework of carbon neutrality and sustainable development. Our conclusions are as follows: At first glance, it appears investment based on the principle of carbon neutrality and sustainable development (sustainable investing) may reduce expected returns. In our view, however, this is not necessarily the case. Though achieving carbon neutrality is a process of internalizing the externalities from traditional energy use, increasing costs in the near term and requiring technological breakthroughs and the further development of rules in the medium term, we believe sustainable investing would not necessarily lead to a decline in returns. In addition, as the world strives to achieve carbon neutrality, opportunities and risks vary among markets with different resource endowments and relative positions on the value chain. We think making active decisions and doing rigorous research are the key to realizing investment returns and guarding against risks.

Second, we believe combating climate change and abiding by sustainability principles will have profound medium- and long-term effects on industries, industrial structure and regional economies. In our view, implementing the principles of carbon neutrality will generate far-reaching implications for production, energy, financials, technologies, consumption, and relative geographical advantages and landscape. We suggest paying attention to a number of issues and trends: (1) the growing utilization of clean and renewable energy; (2) the mounting financial risks to industries with large carbon footprints; (3) recycling of resource amid transformation towards a circular economy; (4) the positive role of advanced technologies in "green energy" use and energy conservation; (5) the reshaping of regional economies; and (6) low-carbon consumption.

Third, we identify potential winners and losers in a wide range of industries amid the goal toward carbon neutrality and sustainable development based on the views of CICC sector analysts. We also compile the CICC China Carbon Neutrality Investment Index (CCCNII). The market cap-weighted CCCNII and the equal-weighted CCCNII have registered annualized returns of 17.2% and 25.1% since 2009, outperforming major benchmark indices. They have delivered notable excess returns in the past 3 years, partly driven by gains from the solar-power and electric-vehicle value chains.

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_12

From an economic perspective, achieving carbon neutrality is essentially a process of changing the way people internalize negative externalities from traditional human activity and production. We think this process will also generate a fundamental shift in how people invest.

This chapter focuses on a number of topics relating to sustainable investment and asset management. In particular, we aim to answer the following three questions:

(1) How will sustainable investment affect potential investment returns? Will it necessarily reduce expected investment gains?
(2) How will following carbon neutrality principles affect the structure of the industries? What trends will it bring to industries?
(3) Which sectors will benefit from carbon neutrality and sustainable development? Which sectors will be negatively impacted? How can investors capitalize on opportunities from carbon neutrality and hedge against risks?

Overall, we draw the following conclusions:

Sustainable investing will not necessarily reduce investment returns. Under the investment framework based on carbon neutrality and sustainable development, environmental externalities from human activities that were not fully reflected in previous investment decisions are now taken into consideration. While sustainable investing seemingly imposes extra restrictions on investments and may reduce expected returns, it may also help balance short-term costs with medium/long-term returns. Additionally, sustainable investment based on carbon neutrality and sustainable development provides investors with additional information on corporate fundamentals. We also think carbon neutrality may trigger a technological revolution. As such, we do not believe sustainable investing will necessarily reduce investment returns, though whether it would provide a substantial boost to returns remains to be seen. Making active decisions and doing rigorous research are of great importance.

Combating climate change and following the principles of carbon neutrality and sustainable development represent a new industrial revolution, which will impact industries, the industrial structure and regional economies significantly in the medium and long term. We believe they will bring about far-reaching implications for production, living environments, energy, financials, technologies, consumption, and relative geographical advantages and landscape.

We suggest paying attention to a number of issues and trends: (1) rising utilization of clean and renewable energy, (2) the complexity of financial analysis, and mounting financial risks to industries with large carbon footprints, (3) resource recycling amid transformation towards a circular economy, (4) the positive role of advanced technologies in "green energy" use and energy conservation, (5) reshaping of regional economies, and (6) low-carbon consumption.

Potential winners and losers: We identify potential winners and losers under carbon neutrality within a wide range of industries based on the views of CICC sector analysts. We also compile the CICC China Carbon Neutrality Investment Index (CCCNII). The market cap-weighted CCCNII and equal-weighted CCCNII have registered annualized returns of 17.2% and 25.1% since 2009, outperforming major benchmark indices. They have delivered notable excess returns in the past 3 years, partly as a result of gains from the solar-power and electric-vehicle value chains.

12.1 How Will Following the Principles of Carbon Neutrality and Sustainable Development Affect Potential Investment Returns?

This is a general question, but investment institutions and researchers have yet to reach a consensus. We try to answer this question by exploring the following two parts.

12.1.1 Existing Framework for Building Sustainable Investment Portfolios and Its Potential Challenges

12.1.1.1 Why Should Investors Focus on Carbon Neutrality?

In previous chapters, we elaborated on why humans should place emphasis on carbon neutrality and sustainable development. In this chapter, we will focus on why investors should attach importance to these two issues.

Overall, the reason why investors should pay attention to carbon neutrality and sustainable development can be divided into financial (affecting investment returns) and non-financial (complying with laws and industry requirements) factors.

First, sustainable investment has attracted wide attention from the global financial and investment industries. In order to fulfill the Paris Agreement, an international treaty on climate change, more than 275 large asset-management institutions in 16 countries created the Institutional Investors Group on Climate Change (IIGCC), and launched the Net Zero Investment Framework that is consistent with the Paris Agreement and can be constantly revised (Fig. 12.1). Institutions that participate in the IIGCC have a combined assets under management (AUM) of US$35trn.[1] We believe the positive response from financial and investment institutions around the world to the call for addressing climate change may push their Chinese counterparts

[1] https://www.iigcc.org/about-us/our-members/.

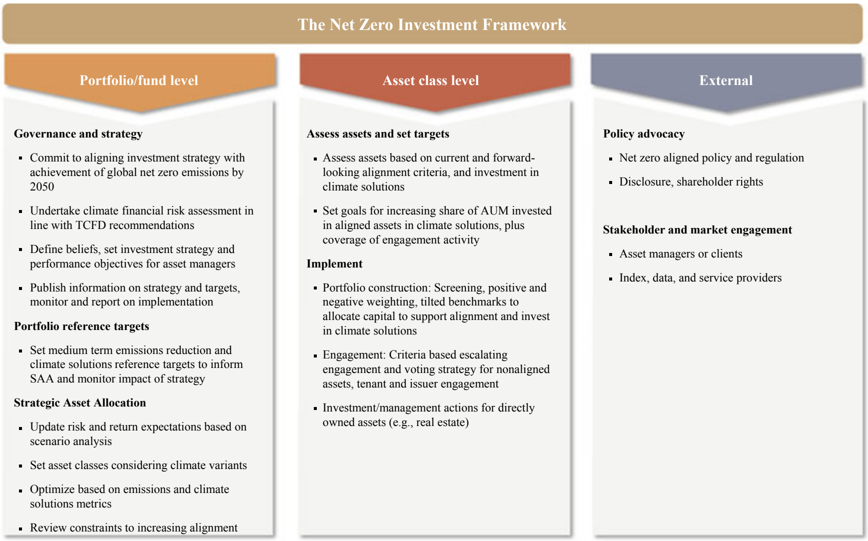


Fig. 12.1 IIGCC's net zero investment framework for consultation. *Source* IIGCC (Net Zero Investment Framework), CICC Research[2]

to follow suit. We think China's financial and investment institutions that take the lead in combating climate change will gain first-mover advantage.

Second, China's commitment to carbon neutrality will also push a wide range of domestic industries (including financials and investment) to formulate codes of conduct on carbon neutrality and sustainable development. China's goal of achieving carbon neutrality by 2060 has drawn wide attention across the country. All domestic industries, including financials and investment, are discussing how the country should achieve this goal. We think the 14th Five-Year Plan and longer-term policy framework will update China's targets and measures on green development based on the commitment to carbon neutrality. In our view, all industries including financials may formulate codes of conduct to help China achieve carbon neutrality and sustainable development. We think this will affect future investment behavior.

Chinese investors just begin to give consideration to compliance with climate treaties. However, as China officially announced the target of reaching peak carbon emissions by 2030 and achieving carbon neutrality by 2060, we think Chinese regulators and domestic financial and investment institutions may introduce disciplined frameworks. In addition, as global asset managers play a greater role in the Chinese market amid further opening-up of the market, their behavior will also affect the performance of the Chinese market and domestic investors will need to focus more on the principle of low carbon and zero emissions in their investment management.

Lastly, as the world steps up efforts to embrace the principles of carbon neutrality and sustainable development, we believe this will also change risks and return

[2] IIGCC, https://www.iigcc.org/resource/net-zero-investment-framework-for-consultation/.

conditions that investors will face. The commitment to carbon neutrality by major economies and strict implementation of the widespread "carbon neutrality and sustainable development" principles in China could be similar to a new round of longer-lasting and farther-reaching worldwide supply-side reform. Moreover, requirements from carbon neutrality and sustainable development are something like a new "energy revolution". We believe this will produce notable and sustained impacts on almost all industries and companies at various positions of different industries, thereby affecting the investment value of many sectors and companies.

Overall, investors need to attach importance to carbon neutrality and sustainable development in all of the three scenarios: (1) fulfilling obligations, (2) capturing opportunities from green development, and (3) guarding against the risk that certain areas face due to carbon neutrality. When exploring international markets and attracting foreign money, Chinese asset managers also need to place emphasis on the principle of carbon neutrality and sustainable development as following this principle has become one of the prevalent options in foreign financial and investment industries.

12.1.1.2 How to Follow the Principle of Carbon Neutrality and Sustainable Development in Formulating Investment Portfolios?

How can investors help achieve the goal of carbon neutrality? Superficially, achieving carbon neutrality and promoting sustainable development seem like a job for industrial companies, and financial institutions are not directly responsible for emissions reduction as they are not large carbon emitters. However, in practice, global financial and investment industries are both following the rules that the Paris Agreement stipulated in their investment process. As investors face new financial and investment principles, the cost of obtaining financial resources will change for different types of companies, thereby affecting corporate and individual behavior.

How do investors follow the principles of carbon neutrality and sustainable development? Currently, in the Chinese market, carbon emission-related regulatory rules are still under development, and the disclosure of emissions data remains incomplete. Therefore, there are only a few quantitative investment portfolios that are built based on the carbon neutrality framework in China. In foreign markets, however, a number of investment portfolios are built based on corporate emissions data in an attempt to curb investment behavior and affect industrial companies. IIGCC released the Paris Aligned Investment Initiative (PAII) in May 2019, and issued the Net Zero Investment Framework for Consultation in 2020, providing asset owners with a preliminary framework on how to build investment portfolios that comply with the Paris Agreement. IIGCC stressed that this framework also applies to asset managers, although it is designed for asset owners.

EU and other relevant institutions have taken the lead in developing investment frameworks that are systematically built based on the goal of carbon neutrality. The investment framework developed by IIGCC whose members are mostly from

Europe is relatively more mature than the others. As such, our analysis is mainly based on IIGCC's investment framework, although this framework is not perfect and it continues to be updated frequently.

Investment portfolio-based emissions reduction via two aspects: According to the Net Zero Investment Framework for Consultation, delivering a "net zero investment strategy" should focus on achieving two alignment objectives: (1) decarbonizing investment portfolios in a way that is consistent with achieving global net zero greenhouse gas (GHG) emissions by 2050, and (2) increasing investment in "climate solutions" that are needed to meet climate goals such as renewable energy, low carbon buildings, and energy efficient technologies.[3]

IIGCC's investment framework covers four major asset classes: sovereign bonds, listed equities, corporate fixed income, and real estate. Further work will be undertaken in Phase II of the PAII to broaden the investment framework to include additional asset classes (infrastructure and private equity), consider the adaptation goals of the Paris Agreement, and address technical issues identified in Phase I.[4] In addition, a large number of asset management institutions are also exploring how to promote low or zero carbon emissions via their investment portfolios.

Potential creation of investment portfolios based on informative corporate emissions data: If data on any individual company's carbon emissions is available, the strategy of building investment portfolios that are aligned with carbon neutrality and emissions reduction will be relatively intuitive. Investment institutions can estimate an investment portfolio's carbon emissions volume or emissions density per unit of investment value based on emissions volume, investment size and proportion of each asset in the portfolio, so as to formulate emissions reduction targets consistent with climate treaties.

12.1.1.3 Potential Problems

We believe the IIGCC's investment framework still needs to be improved further. Under the current conditions, it may face the following issues when it is used to build and manage investment portfolios based on the principle of tackling climate change, reaching carbon neutrality and promoting sustainable development.

Collection of complete, sustained and public carbon emissions data is of great importance to building sustainable investment portfolios. However, such data collection still faces hurdles even in Europe, which has made significant progress in carbon emissions control. In our view, continuous and complete disclosure of carbon emissions data as well as worldwide standard unification might need coordination between policymakers around the world.

[3] Source: https://www.iigcc.org/download/net-zero-investment-framework-consultation/?wpdmdl=3602&refresh=60530ef5ea9bd1616056053.

[4] Source: https://www.iigcc.org/download/net-zero-investment-framework-consultation/?wpdmdl=3602&refresh=60530ef5ea9bd1616056053.

Potential double counting issues in calculating a portfolio's carbon emissions volume: As mentioned earlier, when calculating a portfolio's emissions volume, three types of carbon emissions merit close attention: (1) a company's carbon emissions generated in the course of its operations (scope 1), (2) carbon emissions from generation of electricity and heating that the company purchases from third parties (scope 2), and (3) carbon emissions from the value chain (scope 3), such as the emissions from upstream firms that produce components or the emissions from downstream consumers when using this company's products. In the process of asset allocation, incorrect separation of these three scopes may lead to double counting. For example, if an asset manager invests in both a power plant and the plant's downstream customers, it would be difficult to accurately calculate a portfolio's carbon emission density.

The impact of investor behavior on corporate actions tends to be indirect. While long-only investors who avoid investing in companies with a large carbon footprint, this practice also reduces their impact on these companies. Constraining corporate carbon emissions via investor behavior only has an indirect impact. If long-only investors in the stock market tentatively avoid investing in large carbon emitters, it will in turn weaken their impact on corporate behavior.

The role of short selling in emissions reduction via investment portfolios: Investors cannot affect a company's behavior if they do not hold this company's assets. However, we believe things will change if short selling is allowed. Investors can rely on short selling to hedge against the risk of climate change. They can also leverage short selling to affect the behavior of companies with high emissions. In addition, shorting companies with large carbon footprints can be used to offset the impact of longing firms with limited emissions volume. We believe the short selling system will play different roles in regional carbon emission reduction, as its maturity varies between countries.

Target setting of investment portfolios under IIGCC's investment framework for carbon neutrality and climate change is displayed in Fig. 12.2. The strategic asset allocation (SAA) under IIGCC's carbon neutrality-based investment framework is presented in Fig. 12.3.

12.1.2 How Will the Real Investment Returns Be Affected by Following the Principles of Carbon Neutrality and Sustainable Development?

As the notion of carbon neutrality and sustainable development is becoming increasingly popular in recent years, investment research institutions and other organizations have paid more attention to the impact of these principles on potential investment returns. In particular, sectors related to solar power and electric vehicles (EVs) have significantly outperformed the overall market. Driven by policy support around the world and the plunging cost of EVs, the era of grid parity for solar power plants

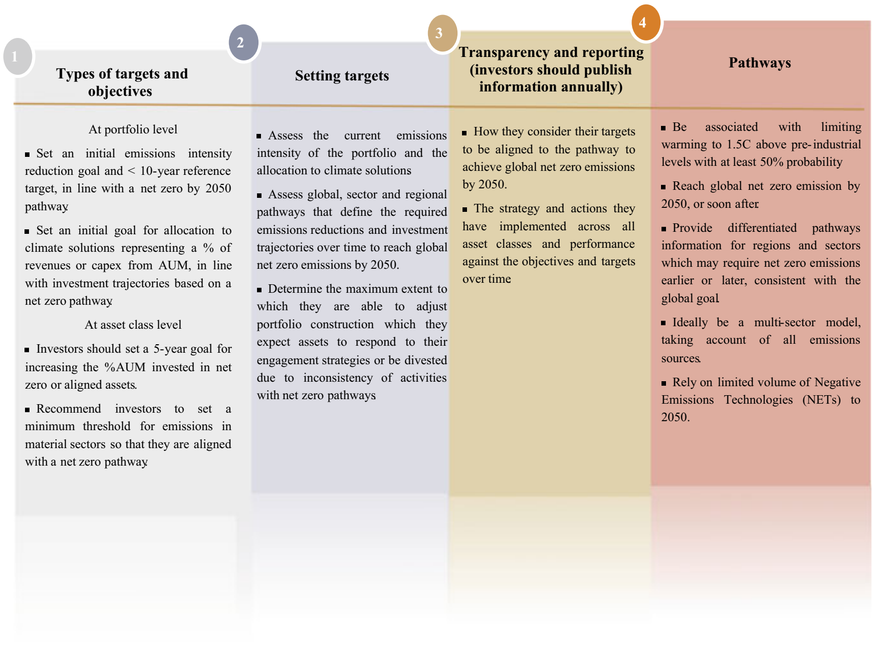


Fig. 12.2 Setting targets for investment portfolios under IIGCC's Net Zero Investment Framework. *Source* IIGCC (Net Zero Investment Framework), CICC Research[8]

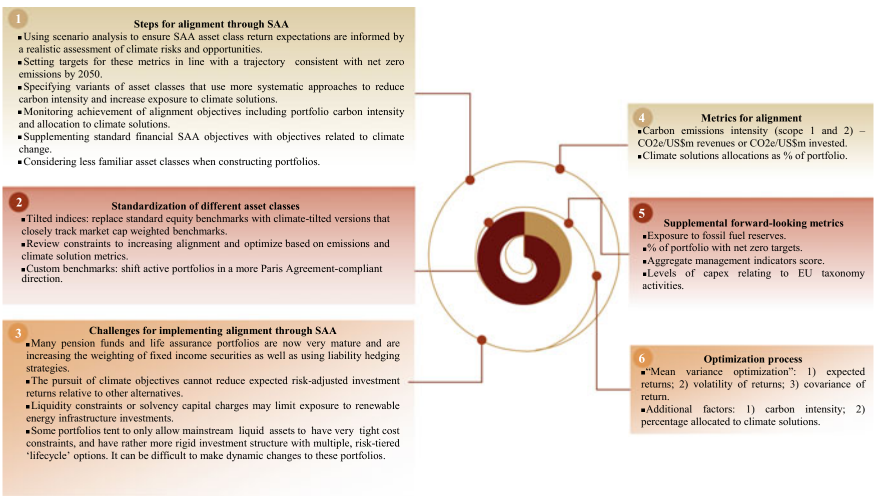


Fig. 12.3 Steps for alignment through Strategic Asset Allocation (SAA) under IIGCC's Net Zero Investment Framework. *Source* IIGCC (Net Zero Investment Framework), CICC Research[9]

is coming and the replacement of traditional fuel vehicles by EVs is also accelerating globally. This trend has also sparked discussions about the relationship between following principles of sustainability and reaping investment returns.

For example, in a research paper released in April 2020, MSCI stated that[5] from December 2009 to December 2019, the environmental, social and governance factor cumulatively contributed 1.88 percentage point to the top 20 ESG funds' returns, with more than 80% of those returns occurring in the last 4 years of the study period. Other studies such as research by G Badía (2018) and JC Mollet (2014)[6] show that there are no statistically significant differences between the performance of high- and low-rated portfolios built based on social responsibilities and carbon neutrality.

Our views and analysis are as follows:

If investing based on the principles of carbon neutrality and sustainable development can have a clear and positive impact on investment returns, we believe this would contribute to achieving carbon neutrality without government support or legal restrictions and mandates. As the Nash Equilibrium shows, if a strategy can benefit all players in a game, this strategy is very likely to be naturally chosen in an entire country without additional government support or legal constraints. However, it remains unclear whether a country can achieve carbon neutrality without government support or legal restrictions due to the following reasons:

Abandoning fossil fuel technologies and pursuing carbon neutrality represent a revolutionary initiative to be undertaken by humanity voluntarily. It is a process of internalizing externalities from the use of traditional energy. It will increase a country's short-term cost, which is clearly a near-term challenge, especially for companies and individuals that rely heavily on traditional energy.

The goal of achieving carbon neutrality is a process of self-disciplined technological innovation and revolution. We believe this process needs the support of capex in the short and medium term, which can create both winners and losers. In the long term, direct or indirect benefits of this revolution will remain uncertain and unpredictable, although potential gains might outweigh the cost, especially for an entire country or the whole world. For example, in order to cut carbon emissions, automakers need to invest heavily in advance. However, the rising penetration of EVs amid emissions reduction is also a revolution in the auto industry, given that the interconnection of intelligent vehicles may effectively improve travel experience and efficiency.

Whether costs and benefits from carbon neutrality can be reasonably allocated between different groups or production to some extent depends on the design of systems which also affects the potential investment returns. The specific mid- and long-term impact of carbon neutrality on a country's capital market indices also

[5] https://www.msci.com/www/blog-posts/quantifying-esg-fund/01760099215#:~:text=Over%20the%20entire%20analysis%20period,seen%20in%20the%20exhibit%20above.

[6] https://www.efmaefm.org/0EFMAMEETINGS/EFMA%20ANNUAL%20MEETINGS/2019-Azores/papers/EFMA2019_0220_fullpaper.pdf,
https://www.zora.uzh.ch/id/eprint/100678/1/WP_JM&AZi.pdf.

depends on the country's stage of development and position in the global value chain.

If a country is determined to reach carbon neutrality, we believe taking systematic actions earlier may help the country face lower costs. Our view is echoed by a number of theoretical studies on climate change such as the research paper "The Environment and Directed Technical Change"[7] published in American Economic Review in 2012. If a country will eventually return to the correct path, assuming other conditions remain constant, early "stop loss" can ensure lower costs.

Lastly, it remains uncertain whether following the principle of sustainability can boost investment returns. However, carbon neutrality and sustainable development are external shocks that humans have brought on themselves. Active research and preparations can help enhance returns and lessen risks when facing uncertainties from both carbon neutrality and all other issues. For example, investors who invested in alternative energy and EV reaped solid returns in recent years. They would not have registered such returns if they had not done forward-looking studies on the solar power and EV industries.

Overall, our conclusion is consistent with the view in the article *"Responsible Investing: the ES-efficient Frontier"* published in Journal of Financial Economics. Carbon neutrality is an entirely new topic that investors around the globe are facing. In our view, it will not only affect investment procedures and portfolio building, but will also have an impact on potential investment returns. We think investors can seize opportunities earlier and effectively against risks by making active decisions and doing rigorous research.

12.2 How Will Addressing Climate Change and Following the Principles of Carbon Neutrality Affect Industrial Structures?

Combating climate change and following the principles of sustainability have the potential of fueling a new technological revolution that can revamp the ways energy is used. Like the Industrial Revolution in the past, we believe this technological revolution will affect all aspects of production and how people live, which will generate far-reaching implications for existing industries and the overall industrial landscape.

We think the following impacts on industries and industrial structure merit attention based on the views of CICC sector analysts and existing studies, as well as our research.

[7] https://economics.mit.edu/files/8076.

12.2.1 Increasing Use of Clean and Renewable Energy

Mass adoption of fossil fuels such as coal and petroleum started several centuries ago. Efforts to address climate change and follow the principles of carbon neutrality and sustainable development help cut emissions, save energy and reduce the use of traditional energy that causes heavy pollutions. In addition, we believe these efforts will also stimulate consumption of clean and renewable energy such as solar, wind and hydro power. We think this will push human society to rely more on clean and renewable energy for production and daily life.

Renewable energy industries such as wind power and solar power are coming into a new era around the globe over the past decade, which is one of the signs of the fourth industrial revolution. The world's energy structure is increasingly diversified and will be dominated by clean and low-carbon energy sources. According to BP's Statistical Review of World Energy 2020, the share of non-fossil fuel energy sources in energy consumption rose from 9% in 1980 to 16% in 2019. Annual average growth in the consumption of renewable energy reached 13.7% in the past decade, making renewable energy the only energy source with double-digit consumption growth in the same period. In addition the International Renewable Energy Agency (IRENA) expects renewable energy to contribute almost 36% of global energy supply in 2030.

China played a major role in the transformation of the global energy structure. According to the National Bureau of Statistics (NBS), coal accounted for 57.7% of China's energy consumption in 2019, 1.5 ppt lower than the share in 2018, and the proportion of clean energy expanded 1.3 ppt to 23.4%.

Over a longer period, the proportion of raw coal production within the China's total energy production trended downward from 74.2% in 1990 to 68.6% at end-2019 (Fig. 12.4), whereas the share of renewable energy expanded from 4.8% to 18.8% in the same period. In addition, raw coal and crude oil combined made up 92.8% of China's energy consumption in 1990, and the aggregate share of hydro, nuclear, and wind power rose from only 5.1% in 1990 to 15.3% at end-2019. China's world-leading adoption of non-fossil fuel energy facilitated the country's transformation towards clean energy sources. As of 2019, China's cumulative installation volumes of hydro, wind and solar power were among the highest around the world.

12.2.2 Mounting Financial Risks to Industries with Large Carbon Footprints

In Chap. 4, we discussed the status quo, existing problems and policy recommendations for "green finance". We believe efforts to address climate change and follow the principles of sustainability will lead to at least two changes in the financial industry:

Under a financial analytical framework, a new factor—sustainable development—is added, making financial investment, pricing, risk measurement and regulation complicated. Putting aside carbon neutrality, a financial analytical framework needs to include factors that are mostly limited to economic and financial returns. However, when considering carbon neutrality and efforts to address climate change, externalities arising from resource and energy utilization could be internalized. The process of financial decision making, regulation and system design will become more complicated. In the previous section, we stated that following the principles of carbon neutrality and sustainable development will make the process of building investment portfolios more complex. We believe this is probably only one of the impacts on the financial industry from carbon neutrality.

Under the principles of carbon neutrality and sustainable development, a number of industries that are closely related to traditional energy sources or emit high levels of carbon (e.g. petroleum, coal and raw material processing) may lose their luster. We believe this will create large uncertainties in the value of financial assets related to traditional industries (e.g. loans and equities), thus heightening the risk of bad debts and defaults.

We believe this problem is particularly striking in China. The outstanding mid- and long-term loans that Chinese financial institutions issued to heavy industries with large carbon footprints totaled Rmb9.54trn (as of December 3, 2020, see Fig. 12.5), accounting for 86% of the total balance of mid- and long-term loans to the entire

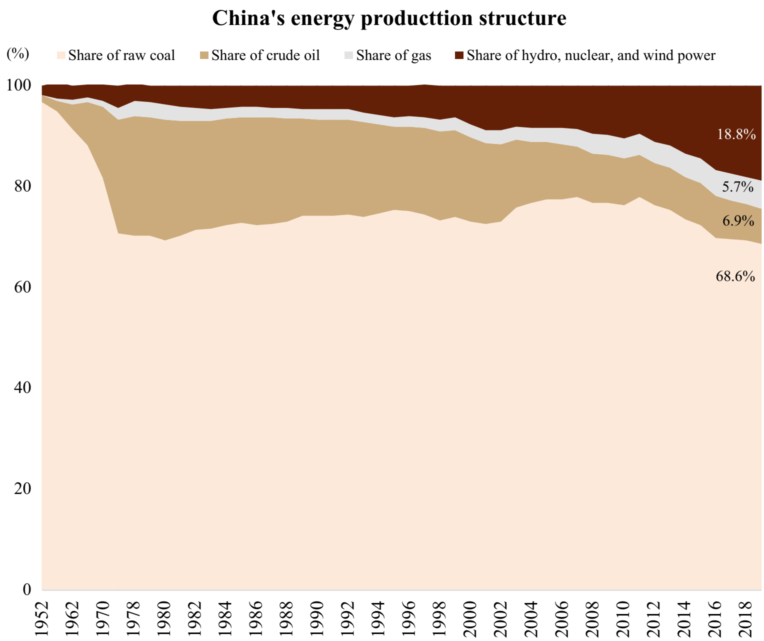


Fig. 12.4 Coal output as a percentage of China's energy production has contracted, while the share of renewable energy has increased considerably. *Source* Wind Info, CICC Research

[8] IIGCC, https://www.iigcc.org/resource/net-zero-investment-framework-for-consultation/.

[9] IIGCC, https://www.iigcc.org/resource/net-zero-investment-framework-for-consultation/.

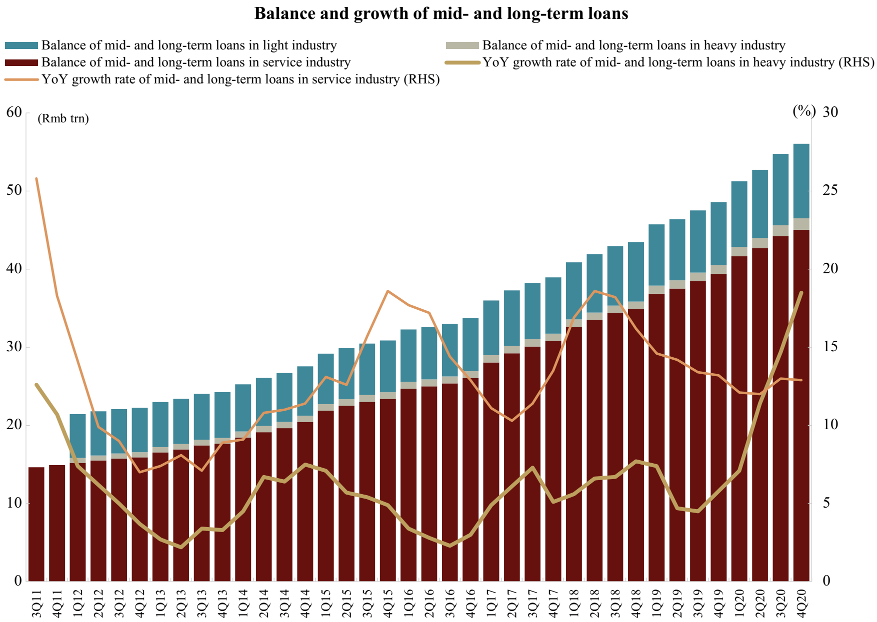


Fig. 12.5 Growth rate of mid- and long-term loans in heavy industry keeps increasing. *Source* Wind Info, CICC Research

secondary sector. The heavy chemical industry now faces strong pressure to transform, which we believe is technologically challenging and will last for some time. In our view, additional requirements from carbon neutrality may reduce market demand for products from heavy industries, heightening the risk to banks with exposure to these industries.

12.2.3 Resource Recycling Amid Transformation Towards a Circular Economy

Production of basic materials such as steel, nonferrous metals and cement accounts for a very large share of China's total carbon emissions. Implementing the idea of "circular economy" in these industries could be one of the most important options for China to reduce carbon emissions and reach carbon neutrality. In "The Circularity Gap Report 2021", the Circle Economy organization stated[10] that only 8.6% of the world's economic resources are currently participating in the practices promoted by the "circular economy". Simple practices such as reducing usage of raw materials can reduce the global emissions and total material footprint by 39% and 28%.

[10] https://www.circularity-gap.world/2021.

It is particularly important for the steel, cement, fertilizer and plastics industries to transform and accept the concepts promoted by the notion of circular economy and considerably raise the recycling rate of key materials. We believe China's demand for crude steel and cement is likely to shrink as its population begins to contract and the urbanization rate decelerates. Energy Transitions Commission estimates steel output based on recycling of steel scrap as a percentage of total steel production will rise from less than 10% at present to 60% in 2050.[11] In the cement industry, recycling potential is limited, but modification of building design and material quality may almost halve cement demand compared to current practices. According to the Energy Transitions Commission, 52% of China's plastics demand could be met by recycled plastics thanks to advancement of physical and chemical recycling technologies. Thus, reducing the use of and recycling of raw materials are of vital importance to carbon emissions reduction.

Looking at the steel industry as example, as steel production relies heavily on fossil fuel energy such as coal, the steel industry accounted for 18% of total carbon emissions among all energy-consuming sectors in China in 2017, according to CEADs. In other words, emissions reduction in the steel industry is crucial for China to achieve carbon neutrality. Chinese Academy of Engineering estimates recycling 1tonne of steel scrap can save 4.3tonnes of iron ore, 1tonne of raw coal, and 1.7tonnes of water, i.e. reducing 1.6tonnes of carbon dioxide emissions. Energy Transitions Commission expects steel scrap supply to grow 10% every year and its price to plunge as a growing number of vehicles, buildings and other equipment reach their designed lifespans. The World Steel Association estimates China's annual steel scrap supply will be around 300–400mn tonnes in total in 2050, which can be used to replace natural resources to save raw materials and reduce carbon dioxide emissions.

12.2.4 The Positive Role of Advanced Technologies in "Green Energy" Use and Conservation

The process of reaching carbon neutrality itself is a technological revolution. The positive role of technologies in carbon emissions reduction cannot be overestimated. Their positive role includes at least two aspects:

Technological advances hold the key to full-scale utilization of renewable and clean energy. For example, incremental photovoltaic (PV) installed capacity rose from 16 GW in 2010 to 105 GW in 2019.[12] We believe technological advances served as a fundamental driver for the strong growth. Innovations in silicon wafers, cells and other modules not only enhanced the power of PV panels, but also reduced the manufacturing cost.

The price of polysilicon modules has dropped from US$2/W to around US$0.2/W. The lower manufacturing cost of PV modules has also pushed down the average cost

[11] https://www.rmi-china.com/static/upfile/news/nfiles/ETC.pdf (source in Chinese).

[12] http://guangfu.bjx.com.cn/news/20200115/1036603.shtml.

of solar power generation. According to IRENA, the average cost of global PV power stations dropped from US$0.378/kWh in 2010 to US$0.068/kWh in 2019,[13] close to or even below the cost of traditional energy-based power stations, making solar power generation more attractive around the world.

However, electricity generated by solar and wind power plants cannot be fully connected to power grids at times, and curtailment occurs due to a number of problems such as intermittent production and ineffective peak shaving.

The combination of energy storage technologies and renewable power generation helps store the electricity that cannot be transmitted to power grids immediately and reduce the volatility of electricity transmission. The mass adoption of electrochemical energy storage systems is less costly than before thanks to technological advancements in lithium-ion batteries and further cost contraction.

Apart from supply-side electricity storage, ultra high-voltage (UHV) power transmission has effectively resolved the problem of long-distance power transmission that renewable power plants face. It paves the way for mass development of quality renewable energy in northwestern China.

Technological advances create important ways to conserve energy. According to a report on China's energy consumption in the construction industry, buildings accounted for 21.7% of China's total energy consumption and made up 21.9% of the country's carbon emissions in 2018.[14] Reducing carbon emissions related to buildings is of vital importance for China to achieve carbon neutrality. In particular, technological advances hold the key to reaching this goal.

For example, technological improvements to buildings' outer protective structure can reduce the use of heating and cooling systems. Energy use technologies such as solar power systems and heating based on ground-source heat can effectively convert solar and geothermal energy into heat and electricity to meet the needs of production and daily life. In addition, installing reclaimed water and rainwater recycling systems in buildings can considerably enhance resource recycling efficiency and reduce the negative impact of buildings on the environment.

12.2.5 Low-Carbon Consumption

Low-carbon consumption is key to carbon emissions reduction in the end market. Consumption is the sole end and purpose of all production activities, and personal consumption is the final source of carbon emissions. Chinese consumption is maintaining strong growth momentum. Consumer spending has contributed more to economic growth than investment, and now serves as a driver of economic growth. The transition period for consumption upgrading also presents opportunities for consumers to develop the habits of green consumption and green lifestyle. If these opportunities are missed, the economy would face higher transitional costs due

[13] https://www.irena.org/publications/2020/Jun/Renewable-Power-Costs-in-2019.

[14] https://www.cabee.org/site/content/24020.html.

to the vicious circle of mass production, ever-higher levels of consumption and a growing number of disused materials. We believe it is of vital importance that China places increasing strategic emphasis on a low-carbon lifestyle.

Green consumption has penetrated almost all aspects of human life such as clothing, food, shelter and travel. Environmentally friendly and resource-saving consumption has become mainstream as disposable income per capita rises further, consumers adopt "green" lifestyles, and consumption upgrading is increasingly apparent.

The UN Environment Programme (UNEP) released a report[15] in 2017 showing that half of Chinese consumers are willing to pay a premium of up to 10% for sustainable products.[16] Meanwhile, China released a report in 2019 on a survey of domestic green consumption. According to this report, the concept of green consumption is increasingly popular among Chinese consumers, with 83% of the respondents saying they were in favor of green consumption behavior (47% showing strong support for such behavior). In addition, according to another report on household low-carbon living and consumption, 54% of the respondents said they would consider energy conservation, low utilization cost, and environmental friendliness when buying home appliances. Overall, the concept of energy conservation and low-carbon consumption is increasingly popular among Chinese consumers, and a growing number of Chinese people live a green lifestyle.

12.2.6 Reshaping of Regional Economies

A country is unlikely to gain first-mover advantage in the process of the carbon neutrality revolution unless it formulates strategies based on local economic conditions, strengths and weakness. How effective a country or a region is in responding to the revolution could be affected by a number of factors such as the extent of its reliance on traditional energy sources, expertise of domestic manufacturers, its position in the global value chain, and its technological innovation capabilities.

The cost of carbon neutrality transformation would be lower if a country starts the transformation earlier. Developed economies have natural advantages in this aspect. Theoretical studies[17] show that the sooner the transformation starts, the lower the cost would be. In developed economies, their technologies are more advanced, and sectors with lower carbon emissions account for a large proportion. As such, they are more likely than other economies to achieve carbon neutrality. In other words, they have gained first-mover advantage.

We think economies that rely heavily on traditional energy sources will face strong challenges in the medium and long term. These economies can be divided into two

---

[15] This report is titled Consumer Awareness and Behavior Change in Sustainable Consumption.

[16] https://www.oneplanetnetwork.org/sites/default/files/en_report_on_consumer_awareness_and_behavior_change_in_sustainable_consumption_in_china-final.pdf.

[17] https://economics.mit.edu/files/8076.

groups: resource-rich economies (such as the Middle East countries, Russia and Australia), and resource-depleted economies like China and Japan.

We think economies with stronger manufacturing industries and advanced technologies are more likely to gain advantages in the transformation towards carbon neutrality. China's alternative energy value chains, especially the solar power value chain, have obtained a global competitive edge following years of efforts. If China can retain the competitive edge, we believe this advantage will also contribute to its transformation towards carbon neutrality.

12.2.7 Impact of Carbon Neutrality on Each Industry, Based on Views of CICC Sector Analysts

We identify the sectors that may benefit from carbon neutrality and sustainable development and the sectors that could be impaired, based on CICC sector analysts' forecasts of opportunities and challenges (Table 12.1). Our analysis focuses on four factors: (1) current carbon emission, (2) the magnitude of policy support and regulatory pressure, (3) "green premium" (additional cost from widespread adoption of the most advanced clean technologies), and (4) social awareness of social and environmental governance (measured by whether companies issue social responsibility reports and disclose full data).

12.3 How to Capture Investment Opportunities from Carbon Neutrality and Guard Against Risks?

In this section, our analysis focuses on two parts:

We discuss how to capture opportunities and avoid risks, based on CICC macro and sector teams' views on carbon neutrality.

We analyze existing indices on carbon neutrality and sustainable development, and compile the CICC China Carbon Neutrality Investment Index (CCCNII).

12.3.1 Investment Opportunities and Risks from the Carbon Neutrality Investment Theme

We suggest paying attention to the following issues when analyzing investment opportunities from carbon neutrality:

Achieving carbon neutrality is a long process, and relies heavily on technological advances. Our views on both investment opportunities and risks are based on current

Table 12.1 Potential winners and losers amid carbon neutrality

Sector	Current Emission	Policy	Green premium	Social manage-ment	Description
Coal					Goal: Demand for coal reaches its peak to realize the replacement by renewable energy Pathway: Decrease the demand for coal, CCS, increase the efficiency of mining Trend: Clean coal, transformation of coal enterprise
Non-ferrous					Pathway: Eliminating outdated production capacity, restricting the investment of high energy-consuming production capacity, and promoting metal recycling Trend: Production capacity optimization, recycling, and transfer to resource-rich areas
Oil & gas					Goal: Demand peaking as soon as possible to realize the replacement of renewable energy Pathway: CO2 flooding enhanced oil recovery technology Trend: Gradually achieve full exit and corporate transformation
Construction materials					Pathway: Technological transformation of the technical route, reduction in the construction process, promotion of energy-saving products and application of energy-saving systems during operation Trend: Carbon reduction in the entire industry chain and life cycle of building materials
Light manufacturing					Pathway: Take furniture as an example, using smart manufacturing technologies such as flexible production to continuously increase the utilization rate of custom home wood Trend: Internationalization of industry standards, recycling of resources and products, low -carbon and efficient customized consumption
Chemicals					Goal: Seek a full life cycle carbon-neutral cycle Pathway: Energy saving and emission reduction, the development of C1 chemistry with carbon dioxide and hydrogen as the core, biomass chemical industry, CCS Trend: Digitization, intelligence, renewable energy, green path
Power					Goal: Use clean electricity to meet growing energy demand Pathway: Improve the economic benefits of clean energy, improve the grid's absorption and energy storage capacity, and improve the flexibility of grid dispatching Trend: Renewable energy integrated into the grid, electricity is parity
Machinery					Pathway: Increase the electrification rate (increase the penetration rate of electrified engineering machinery), and use digital and intelligent production methods Trend: Industrial automation, new energy equipment demand remains high
Electrical equipment					Pathway: Develop scale efficiency of photovoltaic and wind power equipment, improve equipment energy efficiency standards, and popularize distributed power generation system equipment Trend: Gradually entering the era of parity, smart grid
Steel					Pathway: Demand-side control volume, production-side low-carbon emission technology (hydrogen energy metallurgy), market-side combination of carbon tax and carbon trading Trend: Production decline, electric furnace technology replaces traditional blast furnace technology
Toll road					Goal: Achieve carbon neutrality through full mileage electrification (high certainty) Pathway: Expand the scale of EVs and develop energy-saving and emission-reduction technologies Trend: 1) Passenger transportation: increasing passenger car ownership and penetration of new energy vehicles; 2) Freight: "Round to Rail" and "Round to Water"
Railway					Goal: Achieve carbon neutral in 2060 Pathway: Full electrification
Shipping					Goal: Solve decarbonization problems caused by large tonnage and long transportation distance Pathway: LNG, ammonia, hydrogen and electric energy to replace shipping fuel
Airlines & airports					Prediction: Aviation carbon emissions in 2060 may be 230 million tons, about twice that of 2019, making it the most difficult to achieve carbon neutrality Pathway: Provide energy subsidy policies to create a clean aviation fuel market, replace aviation fuel with new energy sources such as hydrogen, and optimize operations to improve fuel efficiency
Auto & parts					Pathway: 1) New energy vehicles: improve safety, improve operating efficiency, shorten charging time, and increase product life; 2) Traditional cars: accelerating the transition to electrification or hybrid Trend: Intelligent electric vehicles enhance the pace of new energy consumption transformation
Agriculture					Pathway: Large-scale farming, the implementation of fine management in manure management, feed efficiency, logistics planning to achieve emission reduction Trend: Modern intensive agriculture, circular agriculture, intelligent agriculture
Home appliances					Pathway: Improve the energy efficiency standards of household appliances, LED replacing ordinary energy - Saving lamps; extensive use of solar water heaters Trend: Energy-saving appliances, recycling
Textiles & apparel					Pathway: Use environmentally friendly and renewable raw materials; use clean energy in the production process; Improve the environmental protection standards
Food & beverage					Pathway: Use biodegradable materials to optimize packaging; increase recycling rate Trend: Lightweight packaging, green transportation
Banks					Pathway: Green credit, green bonds, green asset securitization and green product innovation Trend: Strengthen deposit financial institutions to carry out green credit performance evaluation
Insurance					Pathway: Develop environmental pollution liability insurance, catastrophe insurance, agricultural -related green insurance, green building insurance, clean energy Insurance, etc.
Diversified financials					Pathway: 1) Improve ESG disclosure; 2) Diversification of trust services; 3) Develop carbon market Trend: Economical improvement of financial products
Securities					Pathway: Green securities market innovation, including green bonds, green corporate IPOs; green funds and green PPP, including guiding social capital, and responsible investment concepts

Note In the policy column, red suggests the sector faces regulatory pressure, while green indicates the magnitude of policy support. In the "green premium" column, green indicates negative "green premium", i.e. the cost of decarbonization or clean technologies is lower than that of traditional technologies, while red indicates the other way round; *Source* CICC Research forecasts for economic growth and technological advances. However, economic growth and technological advances may face major uncertainties in the long term.

Carbon neutrality requires changes in energy use, which affects all aspects of production and everyday living. As such, it is difficult to identify investment opportunities and risks from the perspective of all areas.

Nevertheless, given the extent of the impact of moving toward carbon neutrality, we find the following investment themes, based on CICC macro and sector teams' views and our forecasts for technology development and economic growth in both China and around the world in the next 3–5 years.

Clean energy: Companies that produce clean energy or provide relevant services in a bid to increase clean energy supply, including energy-storage service providers and the firms that focus on wind, nuclear, solar, and hydro power, lithium-ion batteries, and hydrogen energy.

Energy conservation and emissions reduction: In addition to the firms that increase clean energy supply, we think beneficiaries of carbon neutrality may also include areas related to energy conservation and emissions reduction such as smart power grids, smart cities, intelligent transport, energy-saving buildings, circular economy, green agriculture, low-carbon consumption, environmentally friendly packaging, carbon capture and storage, as well as green finance.

Indirect changes arising from carbon neutrality: Rising penetration of smart vehicles driven by 5G applications in EVs; demand for relevant services from carbon taxes and trading; and demand for data and services from ESG investment. In addition, as mentioned earlier, regions with different industrial landscapes may have different features due to carbon neutrality, which could present investment opportunities, in our view.

The areas that investors should avoid amid the transition toward carbon neutrality include:

Traditional energy producers and relevant service providers that are slow in transforming, such as companies in the petroleum and coal value chains that are reluctant to take actions in response to carbon neutrality.

Companies that are in the areas with high carbon emissions; lack a strong desire to transform and face high additional cost from carbon neutrality such as producers of steel, nonferrous metals and cement in the manufacturing industry, as well as suppliers of traditional fuel vehicles and companies in the related value chain in the transport industry.

12.3.2 Summary of Existing Carbon Neutrality Indices

12.3.2.1 Existing Carbon-Neutrality Indices

The world's major index companies such as MSCI, FTSE, S&P Global, STOXX, and China Securities Index Co., Ltd. have all released a series of indices on low-carbon economy and green development. These indices have different design plans (see Table 12.2), and can be divided into three categories based on compilation methodology.

Broad-based indices retain all constituents of benchmark indices. They reduce carbon footprint by overweighting stocks with limited carbon emissions and underweighting stocks with significant emissions volumes. Such indices shows performance similar to that of benchmark indices.

Indices focusing on leading stocks in the low-carbon economy exclude sectors or stocks with large carbon footprints and prefer representative companies with low carbon emissions. Such indices have fewer constituents, but are more representative. They also perform better than other indices during market rallies.

Thematic indices: select environmental stocks that benefit from the low-carbon economy. The China Mainland Low Carbon Economy Index and China Low Carbon Index are both thematic indices. Unlike the indices in the first two categories that focus on carbon emissions of listed firms, the thematic indices mainly include environmental stocks that stand to benefit from the low-carbon economy.

12.3.2.2 Carbon Neutrality-Related Funds

In a broad sense, carbon neutrality funds refer to funds whose investment portfolios follow the low carbon principle. Morningstar classifies worldwide low-carbon products based on two factors: carbon risk score and fossil-fuel involvement. According to Morningstar, for a fund to receive the Low Carbon designation, it must have a Morningstar Portfolio Carbon Risk Score below 10 for the trailing 12 months and exposure to companies with fossil-fuel involvement below 7% over the same trailing 12 months.[18] The size and share of Low Carbon Designation™ funds have trended upward since 2012.

In a narrow sense, carbon neutrality funds refer to funds whose purpose is to reduce the global carbon footprint. For example, index funds that passively track low-carbon benchmark indices are typical narrow-sense carbon neutrality funds. The world now has 34 index ETFs and open-ended funds that are related to carbon neutrality, and their aggregate size stands at about US$19bn. Among them, the larger ones were issued mainly in Europe. As the concept of carbon neutrality did not emerge until recently, they were mostly launched in the past 3 years, and they mainly track MSCI and FTSE's low-carbon indices.

12.3.2.3 CICC China Carbon Neutrality Investment Index

The CICC China Carbon Neutrality Investment Index's (CCCNII) constituents include typical Chinese companies that strive to achieve carbon neutrality and are

[18] https://www.morningstar.com/articles/862383/a-closer-look-at-our-new-tools-to-assess-carbon-risk-in-a-portfolio.

Table 12.2 Details on compilation of MSCI, STOXX, S&P, FTSE's low-carbon indices

MSCI			STOXX		
Basic information and preparation method	MSCI global low carbon target index	MSCI global low carbon leading index	Low carbon indices	Low carbon footprint indices	Basic information and preparation method
Index design method	Re-empowerment	Stock selection and re-empowerment	Same components as the benchmark	Compared with the benchmark, the carbon footprint is significantly reduced (>90%), and the risk and return status is good	Compilation method and characteristics
The goal	Minimize carbon emissions (carbon emission intensity and carbon reserves per unit of market value) while limiting the tracking error from the benchmark within the target (default: 30bps), while retaining revenue opportunities, use optimization to reduce portfolio pairs, risk exposure of companies most vulnerable to carbon emissions	Exclude individual stocks based on carbon emission intensity and carbon emissions per unit of market value, then minimize tracking errors while limiting carbon storage per unit of market value within threshold (default value: 50%) by selecting the current low carbon emissions and companies with low fossil fuel reserves to reduce exposure to risks related to carbon emissions	Adopt a carbon tilt, increase the weighting of low-emission companies, reduce the weighting of high-emission companies, and reduce carbon footprint without exception	Excluding the 7 industries with the highest carbon emissions and the 10% of companies with the highest carbon emissions in the remaining industries	

(continued)

Table 12.2 (continued)

MSCI			STOXX		
Optional benchmark index	Any MSCI market capitalization weighted index	Any MSCI market capitalization weighted index	Weight optimization without affecting revenue	Both the announced carbon intensity data and the estimated carbon intensity data are used	
Elimination criteria	Not culled	The 20% of companies with the largest emissions in the benchmark index and the 30% of companies with the largest carbon storage in various industries	Compared with the benchmark, tracking errors are minimal and the risk-reward characteristics are similar		
Optimization/weighting method	Under given constraints, minimize carbon emission intensity and minimize carbon storage per unit of market value	Exclusions based on carbon emission intensity and carbon storage per unit market value	Both the announced carbon intensity data and the estimated carbon intensity data are used		
	Tracking error with reference: Specified target (default value: 30 bps)	Minimize tracking errors	Select all stocks that have announced and estimated carbon intensity data	Supersectors not included: chemicals, utilities, oil and gas, construction materials, tourism and leisure, real estate and basic resources	Stock candidate pool
	Handover constraints: The industry deviation does not exceed 2%, and there is no constraint on the energy industry	Reduce carbon emission intensity and carbon reserves per unit market value by at least 50% (default value)			

(continued)

Table 12.2 (continued)

MSCI			STOXX		
	Industry constraints: The industry deviation does not exceed 2%, and there is no constraint on the energy industry	Handover rate limit: less than 10% of handovers every six months	Sort by ICB Supersector	Supersectors not included: chemicals, utilities, oil and gas, construction materials, tourism and leisure, real estate and basic resources	
			Calculate the Z-score of each supersector	Calculate the Z-score of each supersector	
	Country/region limit: deviation does not exceed 2%	Industry constraints: industry deviation does not exceed 2%	Free float market value is multiplied by the corresponding Z-score carbon intensity factor of the individual stocks. High-allocation stocks with lower carbon intensity, low-allocation stocks with higher emissions	Free float market value is multiplied by the corresponding Z-score carbon intensity factor of the individual stocks. High-allocation stocks with lower carbon intensity, low-allocation stocks with higher emissions	Weighting method
	Risk model: Barra GEM3	Risk model: Barra GEM3	5%	5%	Weight cap
Short-term risk control	Use optimization to reduce the tracking error of the benchmark index	Use optimization to reduce the tracking errors of the benchmark index			

(continued)

Table 12.2 (continued)

MSCI			STOXX	
S&P			**FTSE**	
Basic information and preparation method	S&P global carbon efficient index series	S&P carbon efficient select index series	FTSE ESG low carbon emissions target exposure indexes	Basic information and preparation method
The goal	Measure the performance of benchmark index constituent stocks after excluding companies with no carbon emissions data, companies with high carbon emissions	Measure the performance of companies with lower carbon emissions among the constituent stocks of the benchmark index	FTSE ESG index series reflects the low carbon emission characteristics of ESG index series	Index level
Benchmark index	S&P series index	S&P series index	Reduce carbon emissions at the index level and significantly improve the overall ESG score	The goal
Elimination criteria	Exclude companies with no carbon emissions data	Eliminate high-carbon companies	FTSE series index	Benchmark index

(continued)

Table 12.2 (continued)

MSCI			STOXX	
Selection of constituent stocks and weights	First calculate the weight of a single component stock in the market value of the industry in which it is located in the benchmark index…	Constituent stocks are sorted according to the ratio of carbon emissions to revenue from high to low. If the total weight of the top 20% of the constituent stocks in an industry does not exceed 50% of the industry, all of them are eliminated. If a company exceeds the 50% critical point but does not exceed 55% after being removed, it is still removed; if a company has exceeded the 50% critical point when it is removed or exceeds 55% after removal, the component stock is retained	Standardize the ESG score and carbon emission level of each stock to obtain the Z-score, which is then converted into S-score through the exponential function	Weight confirmation method
	…then use the carbon emission weight adjustment factor to adjust the result of the previous step	The remaining constituent stocks are weighted based on the standard of minimizing the tracking error of the benchmark index, and constituent stocks with too small weights are removed	Bring S-score into the weight calculation formula, and the weight is inclined to companies with high ESG scores and low carbon emissions	

(continued)

Table 12.2 (continued)

MSCI			STOXX	
	Finally, adjust the weight of the previous step again so that the total weight of each industry component's equity is 100% to ensure that the index industry weight is consistent with the benchmark index	The number of constituent stocks ≤ the number of constituent stocks of the benchmark index * 75%	When all constrains are met, the weight of the final constituent stocks is obtained	
Weight restriction	In this series of indexes, only S&P South Africa Domestic Carbon Efficient Capped Index has an equity weight limit of not more than 10%	0.015% ≤ weight ≤ 5%	0.5% ≤ weight ≤ 10%	Restrictions
			Reduce carbon emissions by 50%	
			20% increase in ESG score	

Source MSCI, STOXX, S&P, FTSE, CICC Research

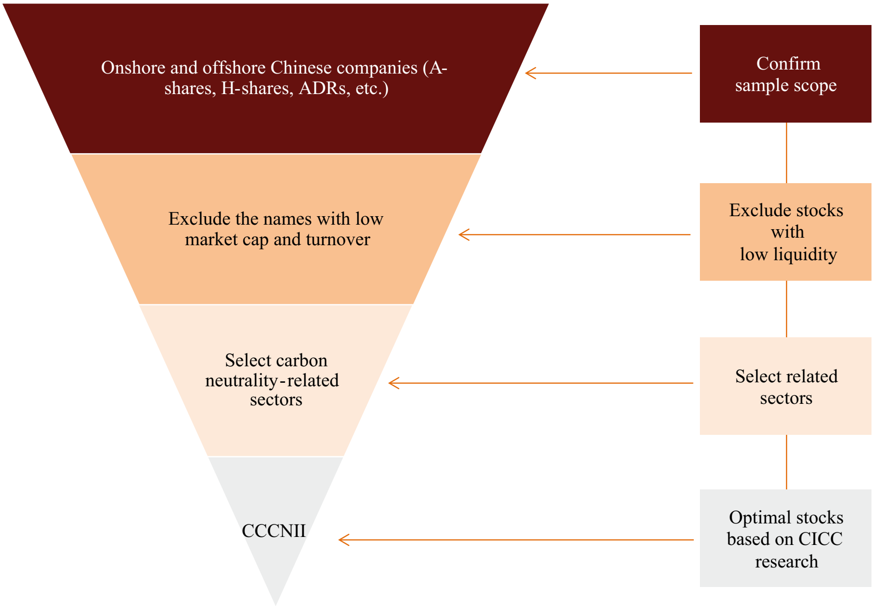


Fig. 12.6 Details on compilation of the CCCNII. *Source* CICC Research

listed on the Chinese mainland or overseas. They can reflect the performance of Chinese industries related to carbon neutrality (see Fig. 12.6).

Our compilation process is as follows:

Sample scope:

Our sample scope is limited to stocks that are publicly traded in China or overseas and have launched IPOs in a specified period. It covers A-shares, H-shares, B-shares, red chips, P chips, and ADRs.

Stock selection:

- Among stocks in the sample scope, the names with market cap and turnover are excluded.
- We select carbon neutrality-related sectors from the perspective of fundamentals. Our constituent candidates include listed firms in areas such as circular economy, environmentally friendly energy, transportation, manufacturing, consumption, agriculture, and city development. Our selection is based on three factors: energy supply, energy demand, and comprehensive changes.
- We choose leading firms in respective areas as final constituents based on the views of CICC sector analysts.

Methodology for constructing the CCCNII:

We review constituents biannually and add newly listed stocks. We adopt market cap-weighted and equal-weighted methods to calculate weight of individual stocks. The weighting of each constituent is up to 10%.

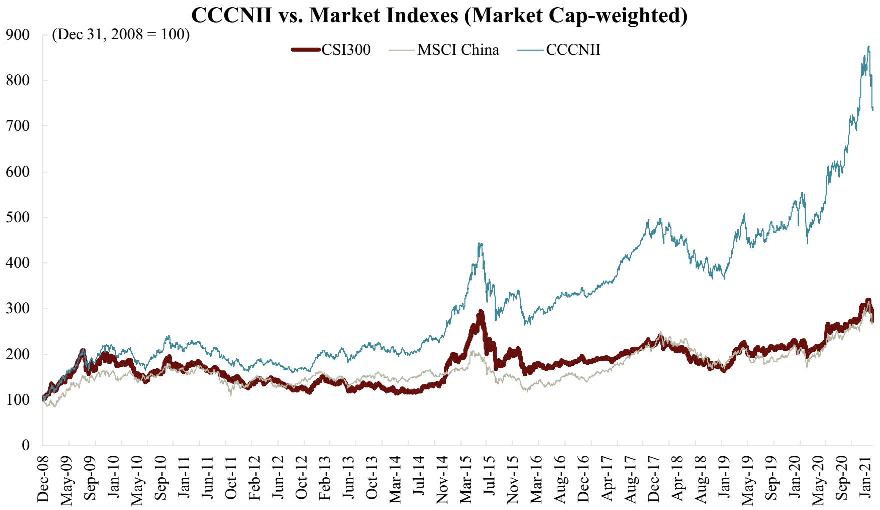


Fig. 12.7 A glance at CCCNII's market cap-weighted performance. *Source* Factset, Wind Info, CICC Research

The market cap-weighted CCCNII and equal-weighted CCCNII have registered annualized returns of 17.2% and 25.1% since 2009, outperforming major benchmark indices. They have delivered notable excess returns in the past 3 years, partly driven by the gains of companies in the solar-power and electric-vehicle value chains.

Comparisons of CCCNII and other main indices are displayed in Fig. 12.7. Detailed constituents of CCCNII are shown in Fig. 12.8.

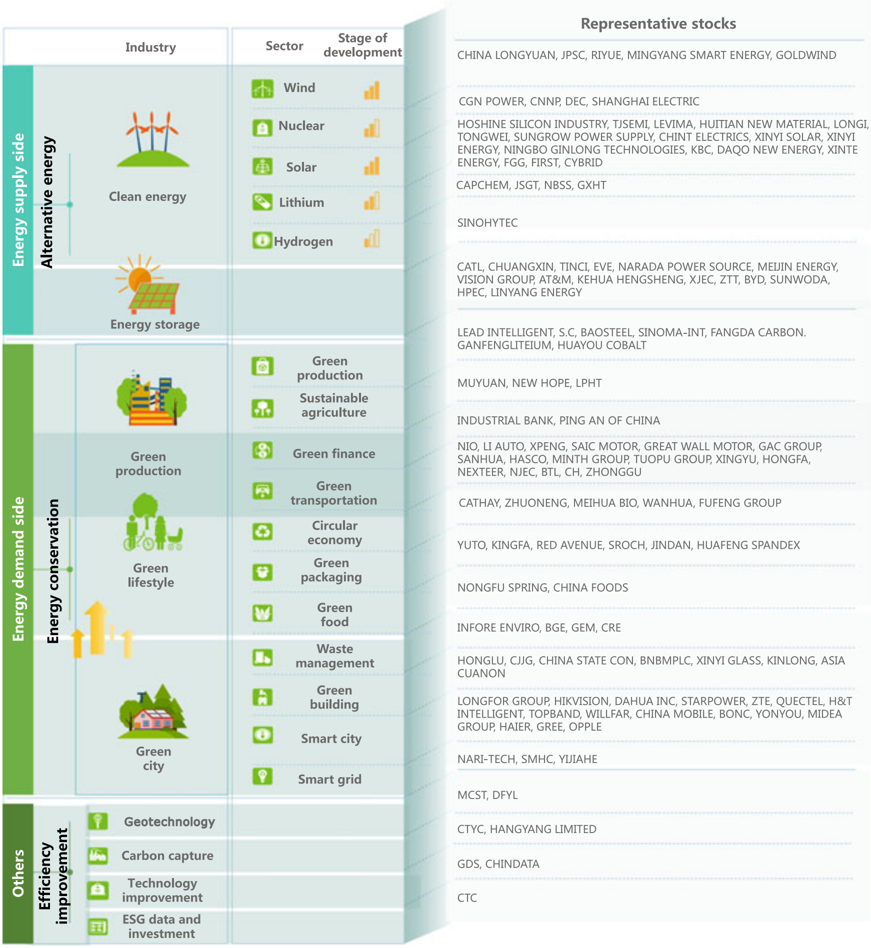


Fig. 12.8 CCCNII's constituents. *Source* CICC Research

Chapter 13
Tackling Climate Change: Global Cooperation and China's Commitment

Abstract Climate issues require a coordinated global response. Greenhouse gases, such as carbon dioxide, remain in the atmosphere for a long period of time and exert a strong influence. Carbon emissions are transnational and intergenerational in nature; they also present a "free-rider" problem due to their role as global public goods. This makes it necessary for nations to go beyond their own decision-making processes and seek global cooperation to solve the problem of climate change. In fact, in the absence of supranational governance bodies, it requires transnational negotiations and consultations to build a global climate governance system. However, under existing technological systems and energy resource endowments, responding to climate change by reducing greenhouse gas emissions may impose constraints on economic development. Looking back at global cooperation in tackling climate change, we find that disputes between countries in politics, economy, science, and technology have posed challenges to the creation of a "fair and effective" global climate governance model. Of course, from a broader perspective, global climate governance has spillover effects, due to its interplay with other fields of international cooperation, such as security, trade, investment, and technology. For example, the carbon border tax proposed by the EU may have a profound impact on current international trade patterns, and high-emission industries could bear the brunt of such actions. In addition, addressing climate change and achieving sustainable development also impose new requirements for the development of global climate finance. Lastly, as a large economy, China will play an important role in promoting the establishment of a global governance system that is fair and reasonable, and focuses on win–win cooperation. For example, we believe China will be an important leader along with the US and Europe in the global response to climate change, and that it will also cooperate with "Belt and Road" countries on climate issues in its process of "going global."

CICC Research, CICC Global Institute, *Guidebook to Carbon Neutrality in China*,
https://doi.org/10.1007/978-981-16-9024-2_13

13.1 Building Fair and Effective Global Climate Governance System

13.1.1 History of International Cooperation in Addressing Climate Issues

According to the timeline of international climate negotiations, we divide the process into four stages: The UNFCCC stage, the Kyoto Protocol stage, the Bali Roadmap stage, and the Durban Platform and the Paris Agreement stage.

- **UNFCCC in 1990–1994**: UNFCCC was the formal starting point of international cooperation in addressing climate change. The UNFCCC established the goal of addressing climate change and it clarified the principles for international cooperation (e.g. principle of fairness and the principle of common but differentiated responsibilities). It also stated that developed countries should take the responsibility before other countries. At this stage, the international community had high expectations on cooperative efforts in coping with climate change.
- **Kyoto Protocol in 1995–2004**: Kyoto Protocol formulated and established specific targets and mechanisms. It set the overall target of 5.2% emissions reduction for developed countries during the first commitment period (2008–2012) and established three flexible mechanisms, namely the International Emissions Trading Mechanism (IET), the Joint Implementation Mechanism (JI), and the Clean Development Mechanism (CDM). However, because the US refused to sign the legal document that included emissions reduction commitments for developed countries, the process came to a halt. At this stage, the international community reassessed the difficulties in tackling climate change issues and various parties adopted more pragmatic approaches. Developed countries also put more pressure on developing countries over emissions reduction.
- **Bali Roadmap in 2005–2010**: The issue of climate change received unprecedented attention from the international community, and all major powers actively participated in addressing climate change. Much progress was made at this stage, including the establishment of the "two-track" approach. Developing countries would need to take actions within their national capacities and began to establish a bottom-up approach with "commitment + regular review" to achieve the relatively flexible target of limiting the temperature increase to within 2°C (i.e. the 2°C target). However, due to the disagreement between countries, the Copenhagen Accord was set aside at the end in 2009. The binding force of the Cancun Agreements in 2010 also turned out to be unsatisfactory.
- **Durban Platform and Paris Agreement in 2011–2015**: This stage began with the *Durban Platform negotiations* in 2011 and further developed in 2012 with the *Doha Amendment to the Kyoto Protocol*. Eventually, the landmark 2015 Paris Agreement further established the models and mechanisms for international cooperation to tackle climate change. This agreement stated that all countries should

contribute to reach peak global emissions as soon as possible, and the goal of capping the global temperature rise below 1.5°C was added through the first round of periodic review. Additionally, the Green Climate Fund (GCF) was established and the internationally transferred mitigation outcomes (ITMO) and sustainable development mechanism (SDM) were proposed.

- However, there were also some problems with the "bottom-up" model of nationally determined contributions (NDCs). In the "2020 Emission Gap Report", the United Nations Environment Programme (UNEP) pointed out that current NDCs remain seriously inadequate for achieving the Paris Agreement climate goals and would lead to a temperature increase of at least 3°C by the end of the century.[1] In addition, it suggests that the Paris Agreement lacked rigorous target management and reward/punishment mechanisms, resulting in challenges to international cooperation.

13.1.2 Discussion on Fair and Effective Governance Model

Given the externalities of climate issues that span a long time frame, how to measure "climate fairness" and establish "fair" and "effective" climate governance models accordingly are the two core issues that draw the most attention in global efforts to tackle climate change.

13.1.2.1 What is Climate Fairness?

Climate fairness is a basic prerequisite for global climate cooperation and an important guide for action. Climate fairness refers not only to the equal rights of all countries, regions and individuals to enjoy the world's resources, but also to the equitable sharing of obligations to stabilize the climate. Furthermore, in the context of international cooperation in tackling climate change, all countries have the same right to enjoy sustainable development.

From an intergenerational perspective, the discussion on "outcome fairness" focuses on the principle of "common but differentiated responsibilities" and respective capabilities. It not only clarified the "common" responsibilities of all countries to deal with climate change, but also emphasized the "differences" and respective capabilities. That is to say, different countries bear different responsibilities according to their impact on climate change, economic condition, and capabilities. The concept of this principle is clear, but there have been considerable disputes and controversies with regards to the specific details involved. For example, it is difficult to determine the responsibility of previous generations, and to hold them accountable for climate

[1] https://wedocs.unep.org/bitstream/handle/20.500.11822/34438/EGR20ESC.pdf?sequence=27&isAllowed=y.

issues. To compensate for their historically larger emissions, developed countries were responsible for not only reducing emissions, but also providing financial, technical and capacity-building support to developing countries. However, in the absence of a well-defined monitoring mechanism, the actual effects were relatively limited.

Moreover, different understandings of "common but differentiated responsibilities" also affect the international community's discussion on distribution of carbon emission credits on an intra-generational basis. The Paris Agreement did not establish rules for sharing the emissions reduction contributions of various countries. Therefore, many countries have carried out research to find solutions that are recognized by the international community. For example, the "contraction & convergence" framework proposed by Global Commons Institute (GCI) in the UK reflected the "grandfather clause"; proposal from Chinese and Brazilian scholars is based on the principle of "equal cumulative emission per capita", proposing to take into account historical emissions when evaluating current emission responsibilities.

13.1.2.2 What is an Effective Governance Model?

Another focus of international climate negotiations is the dispute over whether top-down or bottom-up governance models are more suitable for climate issues. The governance approaches adopted in the stages of UNFCCC and the Kyoto Protocol can be regarded as the preliminary versions of the top-down global climate governance model. However, in the absence of supranational governance bodies, the effects of the top-down institutional design were not ideal. To address these problems, the Warsaw Climate Change Conference 2013 and the 2014 Lima Climate Change Conference introduced the innovative idea of NDCs. The Paris Agreement in 2015 allowed each country to carry out climate reduction actions based on its own national conditions and capabilities. It adopted a bottom-up approach to achieve the goal of reducing emissions and tackling climate change in order to enhance execution and raise the enthusiasm of all countries. However, the bottom-up model also has drawbacks, for example, there is still a certain gap between various countries' NDC targets and the overall global target.

Climate Club may provide a new alternative for effective global climate governance.

According to the club theory (the study of club goods in economics), the successful operation of clubs often depends on a unified set of rules. Members pay "contributions" to join the club and obtain exclusive benefits relative to non-members. The benefits may be provided directly by the club or created collectively by members. Based on this theory, William Nordhaus, the 2018 Nobel Prize laureate in economic sciences, introduced the concept of the "climate clubs" mechanism. In the field of climate cooperation, the "contributions" made by member states to participate in the Climate Club consist of carbon emissions reduction actions and the costs incurred. Climate resources are their common benefits. However, considering the non-exclusiveness of climate change, non-participants are penalized for being free-riders.

Nordhaus'[2] Climate Club relies on the implementation of two rules: (1) an agreement between participating countries to undertake harmonized emissions reductions; and (2) countries that fail to fulfill their obligations are penalized. The agreement envisioned here centers on a "target carbon price that is agreed by the international community", which is the focal provision of an international agreement. The simplest and most effective measure to punish non-participating countries is to impose tariffs on products imported from non-participating countries to club member states. Based on this, Nordhaus used the Dynamic Integrated Climate Change (C-DICE) coalition model to show that with a unified tariff penalty mechanism, participating in the Climate Club would be the best choice for the US. When considering the sum of emissions reduction costs, environmental gains, and trade benefits, participating in the Climate Club would give the US the optimal net gain.

The Climate Club adopts a unified carbon tariffs-based penalty mechanism and the ultimate goal is to have countries take initiatives to reduce carbon emissions. However, in practice, we believe successful operation of the Climate Club requires addressing a number of obstacles.

First, it is challenging to form a unified carbon emissions target price; standards and methods of implementing a unified carbon tariff also require further discussion.

Second, the punishment mechanism can effectively overcome the free rider problem, but international climate cooperation also involves the issue of justice. Designing effective assistance and compensation mechanisms may be of great significance to motivate developing countries to participate in carbon emissions reduction.

Lastly, trade-related carbon emissions are only part of total carbon emissions. The scope of the carbon tariff only covers part of the carbon reduction initiatives by countries around the world, and it remains to be seen whether the tariff can promote global carbon reduction.

[2] Nordhaus W. Climate Clubs: Overcoming Free-Riding in International Climate Policy[J]. American Economic Review, 2015, 105(4):1339–1370.

13.2 Spillover Effects of Global Climate Governance—International Trade and Climate Finance

13.2.1 International Trade: Embodied Carbon and BTA

Embodied carbon refers to carbon emissions associated with the production process of imported and exported goods. With the development of economic globalization, a country's carbon emissions are not only determined by domestic production and consumption, but also by international trade. According to Organization for Economic Co-operation and Development (OECD) data, the scale of carbon emissions embodied in global exports was close to 9bn tonnes in 2015, accounting for about a quarter of global carbon emissions (Fig. 13.1).

From the perspective of the scale and flow of global trade, embodied carbon mainly flows from developing countries to developed countries. Such phenomenon may have three implications. First, developed countries may simply reduce domestic emissions from production by importing goods and passing the carbon emissions (by transferring production) to developing countries. Second, high-carbon-producing industries may move from developed countries to developing ones, which increases the volume of domestic carbon emissions in developing countries. Third, due to technological restrictions, carbon emissions associated with the same production process in developing countries are likely to be higher than those in developed countries, which may eventually lead to a net increase in global carbon emissions (Fig. 13.2).

13.2.1.1 Carbon Emissions Embodied in Trade and the Principle of Fairness

The Intergovernmental Panel on Climate Change (IPCC) proposed adopting Extended Producer Responsibility (EPR) which means that carbon emissions caused

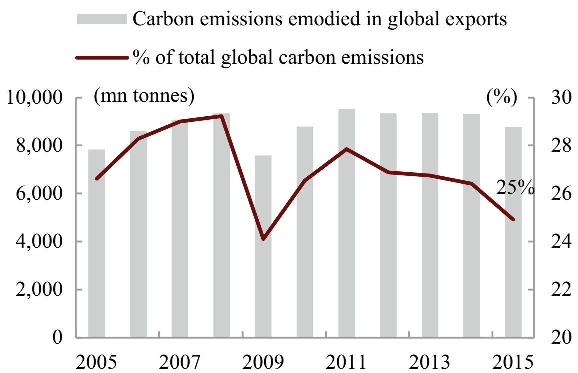


Fig. 13.1 Carbon emissions embodied in global exports accounted for nearly one-fourth of the world's total carbon emissions. *Source* OECD, Our World in Data, CICC Global Institute

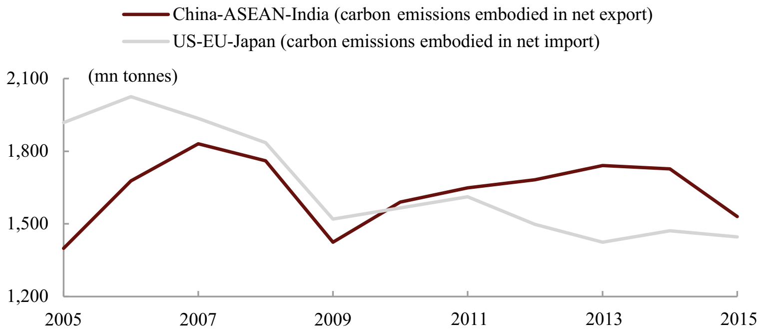


Fig. 13.2 Carbon emissions embodied in trade of world's major economies in 2005–2015. *Source* OECD, CICC Global Institute

by production and exports would be counted toward carbon emissions of production areas while the impact of importing high-carbon emission products would be excluded. However, the development of international trade has highlighted the unfairness of the EPR approach to production areas.

Another accounting method is Extended Consumer Responsibility (ECR). In other words, all carbon emissions in the production process of commodities are borne by consumers. This method is relatively fair to producers, though it also has limitations. It lacks binding force and discourages producers from reducing emissions. To solve this problem, many scholars have proposed the principle of shared responsibility for carbon emissions, which aims to effectively achieve global emissions reduction targets by restricting and controlling carbon emissions on both the production and consumption sides as well as distinguishing between responsibilities of producers and consumers. However, under the principle of shared responsibility for carbon emissions, how to allocate the responsibilities of producers and consumers while establishing a reasonable, clear, and feasible scheme of shared responsibility for international carbon emissions would also pose a challenge.

13.2.1.2 Carbon Emissions Embodied in Trade and BTAs

Border tax adjustments (BTAs) refer to a special carbon emission tariff levied on exported goods that are not taxed in the producing country. BTAs are introduced mainly because developed countries hope to impose tariffs on carbon emission-intensive products imported from developing countries.

The EU started to discuss and study carbon BTAs in the 1990s, and it advocates levying taxes on industrial products imported from countries with loose environmental regulations. The main targets include: (1) reducing global "carbon leakage", in other words, reducing the transfer of production and manufacturing to countries that do not implement strict emissions reduction policies, and (2) creating a "level playing field" and levying carbon tariffs to prevent countries lagging behind in carbon emissions reduction from gaining trade advantages. This could help protect EU companies facing extra emissions reduction costs in the EU carbon emissions trading market, and ultimately enhance the global competitiveness and international influence of the EU. On July 14, 2021, the European Commission adopted the proposal for establishing a carbon border adjustment mechanism.[3] At the same time, the US also held discussions on BTAs, for example, both the American Clean Energy and Security Act of 2009 and the American Opportunity Carbon Fee Act passed in 2014 mentioned carbon tariffs.

However, there are also many controversies surrounding BTAs:

- **Legitimacy**. Does the imposition of BTAs violate the basic rules of the WTO? Carbon tariffs conflict with the WTO's most-favored-nation treatment (MFN) and national treatment (NT) principles. However, WTO rules allow for the introduction of trade restriction clauses under exceptional circumstances, which may provide a legitimate basis for carbon tariffs. When the domestic tax base of a certain type of product is linked to the carbon footprint in the production process, tariffs levied with reference to domestic standards are allowed.
- **Fairness**. Taking into account the distribution of carbon emissions embodied in global trade and trade flows, is the BTAs mechanism promoting trade protectionism in the name of environmental protection and hurting the interests of developing countries? Will the carbon tariffs collected be used for climate cooperation? These questions still need to be answered.
- **Effectiveness**. It remains to be seen if BTAs can effectively reduce global "carbon leakage" and help achieve the ultimate goal of carbon emissions reduction.
- **Feasibility**. How to calculate BTAs? For example, how to calculate the carbon content of imported products, especially products manufactured in multiple countries? How to set an effective and reasonable carbon price?

If the EU promotes the adoption of BTAs, what would be the impact on global trade and the industrial landscape?

- BTAs may change current landscape of international trade. The carbon factor as a new cost factor may have a greater impact on the production side. Developed countries will benefit more, while the competitiveness of related developing countries could be weakened. That said, the inclusion of embodied carbon in the international trading system may also force developing countries to adjust their industrial structures and production methods and move towards clean and low-carbon development.
- Trade pattern of high-carbon industries will bear the brunt of the impact. A report from Boston Consulting Group discusses this impact with regard to the carbon intensity and trade intensity of different industries, and further analyzes the impact of the EU's BTAs on international trade in different industries.[4] For example,

[3] https://ec.europa.eu/info/sites/default/files/carbon_border_adjustment_mechanism_0.pdf.

[4] https://www.bcg.com/publications/2020/how-an-eu-carbon-border-tax-could-jolt-world-trade.

emissions from steel production in Turkey and the US average only half of the emissions from China and Ukraine. If the EU imposes BTAs, the competitiveness of Turkish and US steel in EU imports will be strengthened.

- Lastly, we think BTAs may drive up the prices of corresponding products in the international market, and lead to deteriorating terms of trade and weakening international competitiveness; it could also have a negative impact on developing economies. A research report[5] written by experts from the World Bank and the Peterson Institute for International Economics pointed out that once industrial countries impose carbon tariffs, China's manufacturing exports would decline by one-fifth and those of all low- and middle-income countries by 8%.

13.2.2 Global Climate Finance: Realities and Challenges

13.2.2.1 Global Climate Finance: Realities

The concept of climate finance was born amidst negotiations over funding issues in the United Nations Climate Change Conference. The United Nations defines climate finance as financing and investment activities related to the UNFCCC that could reduce emissions and seek to support mitigation and adaptation actions in order to address climate change.[6] In a broad sense, climate finance covers all investment and financing activities in response to and supporting mitigation of climate change.[7]

In recent years, the scale of global climate finance has grown rapidly. According to a report released by the Climate Policy Initiative,[8] the scale of global climate financing may have reached US$608–622bn (Fig. 13.3), corresponding to a CAGR of around 10.1%–10.5% from 2013 to 2019. Specifically:

- **Geographic flows**: (1) The Asia–Pacific region, Western Europe and North America were the three primary destinations, accounting for 41%, 19% and 17% of global climate finance in 2018; (2) Climate finance that flowed to developing countries grew to US$356bn per year in 2017–2018, indicating a 32% increase from US$270bn per year in 2015–2016[9]; (3) A strong domestic preference continues, as 76% of finance was raised and spent domestically in 2017–2018.[10]
- **Financial sources**: (1) The public sector accounted for 52% of global climate funding sources in 2017–2018 which was higher than the 48% for the private

[5] Aaditya Mattoo, Arvind Subramanian, Dominique van der Mensbrugghe, and Jianwu He, 290919536009. Reconciling Climate Change and Trade Policy. Peterson Institute for International Economics Working Paper Series.

[6] https://unfccc.int/topics/climate-finance/the-big-picture/introduction-to-climate-finance.

[7] https://www.worldbank.org/content/dam/Worldbank/document/Climate/FinanceClimateAction_Web.pdf.

[8] Climate Policy Initiative, Global Landscape of Climate Finance 2019.

[9] Climate Policy Initiative, Global Landscape of Climate Finance 2019.

[10] Climate Policy Initiative, Global Landscape of Climate Finance 2019.

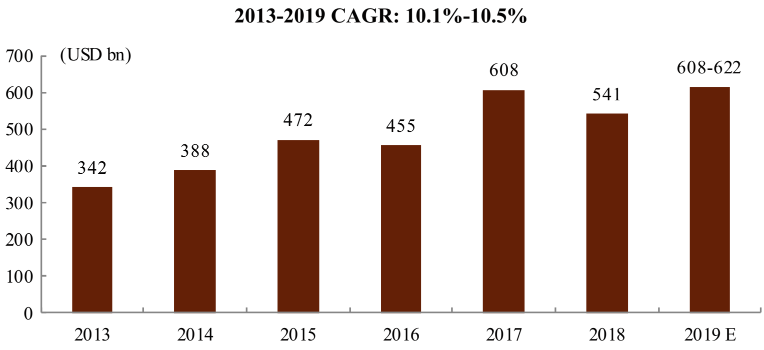


Fig. 13.3 Scale of global climate finance grew rapidly. *Source* Updated View on the Global Landscape of Climate Finance 2019, CICC Global Institute. *Note* CPI statistics seek to capture a non-double-counted estimate of financial flows. Finance provided through some financial instruments such as guarantees, insurance, government revenue support schemes, and fiscal incentives are not counted to avoid double counting and overestimating project investment costs

sector; (2) Global climate finance from the public sector is concentrated at the national level, with governments and state-owned enterprises (including domestic development financial institutions) making up 37% of global climate financial sources; (3) Climate finance from the private sector is concentrated on non-financial corporations, which made up about 27% of global climate financial sources (Fig. 13.4).

- **Financing structure:** The majority of climate finance was raised as debt, which accounted for 66% of total climate finance in 2017–2018, including on-balance sheet credit and bonds. Equity investments made up about 29% of total climate finance while grants and others were 5% (Fig. 13.5).
- Financial mechanisms mainly comprise UNFCCC system and traditional financial markets. The Paris Agreement proposed making finance flows consistent with a pathway towards low carbon emissions and climate-resilient development in the long run. Moreover, financial mechanisms under the UNFCCC framework, such as GCF, the Special Climate Change Fund (SCCF) and the Adaptation Fund (AF), were established. Beyond the UNFCCC framework, there are also some other financial mechanisms such as bilateral and multilateral capital channels, and regional private sector climate finance.

13.2.2.2 Issues and Challenges Facing Global Climate Finance Today

The development of global climate cooperation poses some thorny issues and challenges to climate finance:

(1) **Huge global climate funding gap**. International agencies have different forecasts on funding needs for tackling climate change. According to UNEP forecasts, in order to address climate change, the transformation of the global energy sector will require raising supply-side investment to between US$1.6trn

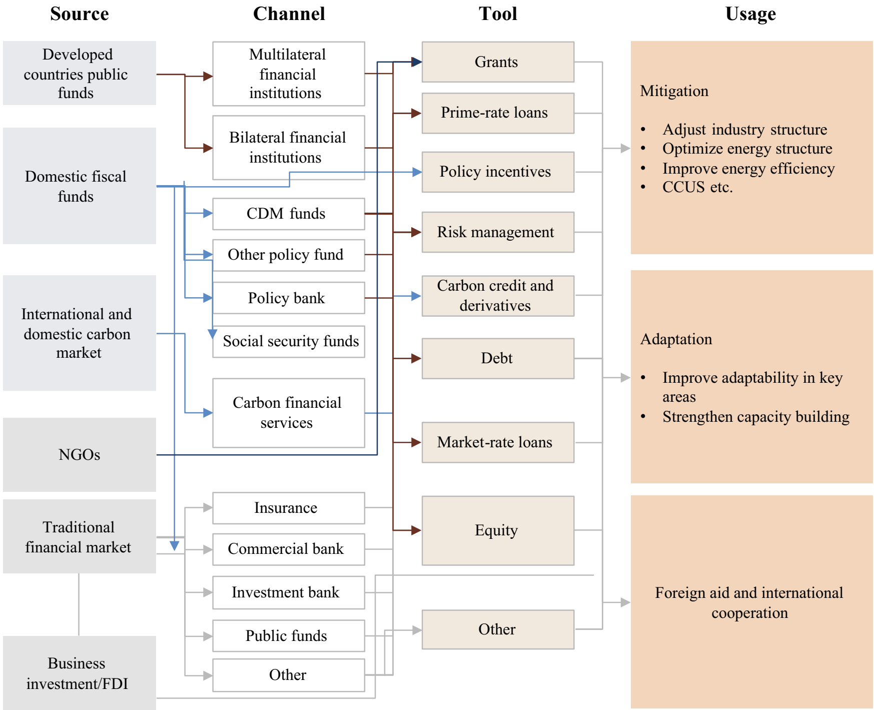


Fig. 13.4 Sources, channels, tools and usage of global climate finance. *Source* NCSC, CICC Global Institute

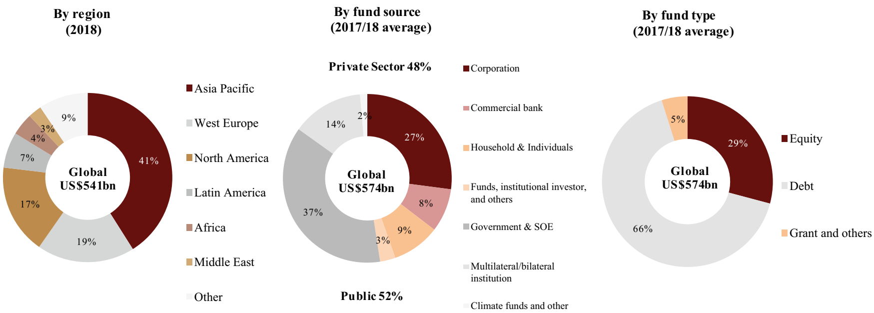


Fig. 13.5 Different perspectives of global climate finance analysis. *Source* CPI Updated view on the Global Landscape of Climate Finance 2019, CICC Global Institute

and US$3.8trn per year in 2020–2050 (Fig. 13.6).[11] Considering the current global annual climate finance of approximately US$500–600bn, we project the annual global climate finance gap to be US$3–4trn in the future. With

[11] https://wedocs.unep.org/bitstream/handle/20.500.11822/30798/EGR19ESCH.pdf.

current climate financing instruments and methods, the financial pressure from the global response to climate change and carbon emissions reduction targets would be high.

(2) **Limitations in scale and efficiency of public funds provided by developed countries to developing countries**. According to provisions in the Paris Agreement, developed countries should commit to mobilizing a minimum of US$100bn each year to assist developing countries by 2025. However, according to OECD data,[12] the scale of climate finance provided by developed countries to developing countries still lagged behind this target in 2016–2018 (Fig. 13.7). Meanwhile, the proportions of climate funds provided by developed countries that are used for mitigation (short-term emission reduction) and adaptation (long-term construction of capabilities) are 70% and 21% respectively, suggesting a mismatch in the structure. Efficiency of the funds still needs to be improved.

(3) **Insufficient private sector investment along with limited effects of market-based and innovative financial tools**. According to statistics by the Climate Policy Initiative, the total scale of climate finance from channels such as market-oriented funds and institutional investment was only US$17bn from 2017 to 2018, accounting for about 3% of global climate finance. Private sector, market-based institutions, and innovative financial instruments played a limited role in global climate finance.

(4) **"Green Swan" events may pose risks to global economic and financial system**. According to the Bank for International Settlements' (BIS) definition, "Green Swan" refers to potentially extremely disruptive climate-related events that could be behind the next systemic financial crisis, such as credit, liquidity, and market risks. At present, the international community's understanding and assessment of this new type of risk is inadequate.

13.2.2.3 Outlook for Global Climate Finance

Bridging the global climate funding gap is a top priority for governments. We believe it is necessary not only to explore breakthroughs and expand the scale of climate finance under the international multilateral mechanism, but also to further innovate climate financing tools and unleash market vitality.

- **Tapping the potential of international multilateral institutions and leveraging social capital investment with public sector funds are also important for climate finance.**
  International multilateral financial institutions were established by a number of member states and they have played an active role in global climate finance. World Bank data shows that every US$1 invested by multilateral development banks in public climate funds mobilizes some US$2–5 in private investment.[13] In

[12] OECD, Climate Finance Provided and Mobilized by Developed Countries in 2013–18.

[13] https://www.huanbao-world.com/a/zixun/2018/1125/62198.html.

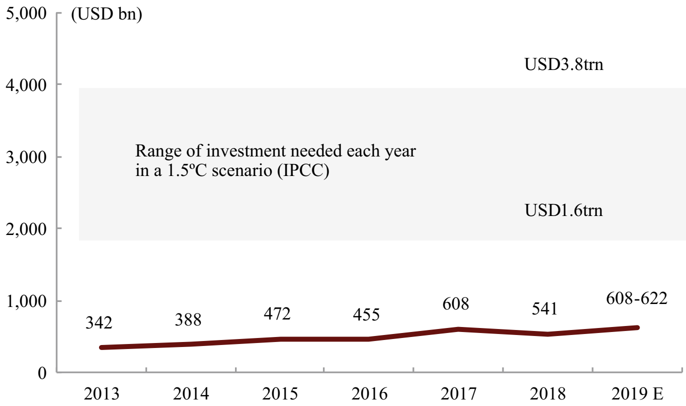


Fig. 13.6 Global climate finance gap. *Source* CPI Updated View on the Global Landscape of Climate Finance 2019, CICC Global Institute

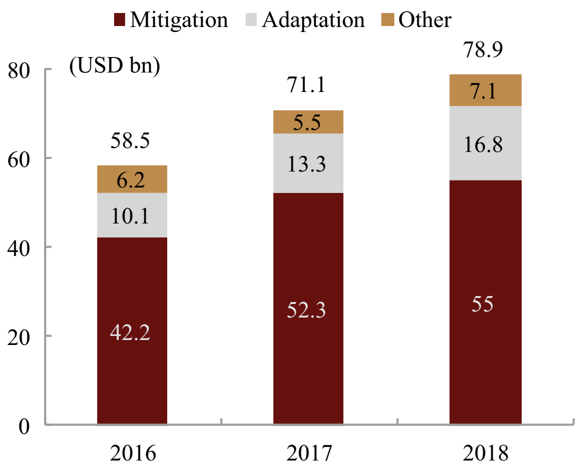


Fig. 13.7 Structure of climate finance provided by developed countries to developing countries. *Source* OECD, CICC Global Institute

recent years, international multilateral development banks have provided large-scale financing to tackle climate change and reduce carbon emissions, and the scale of financing continues to expand. In 2019, the world's seven major multilateral development banks[14] provided a total of US$46.4bn in climate finance, and the CAGR of their climate financing hit 7.0% in 2011–2019 (Fig. 13.8).

[14] Including World Bank, Islamic Development Bank, European Investment Bank, European Bank for Reconstruction and Development, Inter-American Development Bank, Asian Investment Bank, African Development Bank.

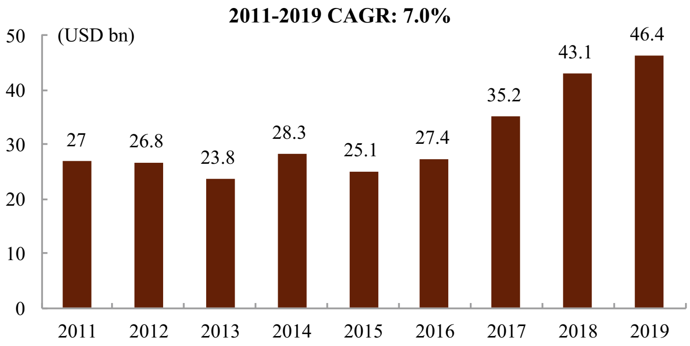


Fig. 13.8 Climate finance commitments of the world's seven major multilateral development banks. *Source* 2019 Joint Report on Multilateral Development Banks' Climate Finance, CICC Global Institute

- **Exploring and innovating climate investment and financing tools**. Countries and regions that lag in developing climate finance could explore mechanisms and models for climate investment and financing tools (such as credit, bonds, and insurance) by launching pilot climate investment and financing projects. They could then innovate products and leverage the investment and financing functions of financial tools in view of local conditions.

- **Improving global climate finance rules, incorporating climate risk assessment, and strengthening climate information disclosure can enhance the financial system's ability to respond to climate change.**
- **Establishing and improving climate risk assessment system**. In the report *The Green Swan: Central Banking and Financial Stability in the Age of Climate Change* published in January 2020, the BIS urged central banks to be vigilant of green swan events and incorporate climate change considerations into their moves to prevent financial risks.
- **Strengthening disclosure of climate information**. Although international organizations and countries have imposed requirements for information disclosure of climate change-related projects, the problem still exists. The main concerns are inconsistent certification standards for climate or green projects and inconsistent levels of information disclosure required in different countries. The International Financial Reporting Standards (IFRS) Foundation, an international authoritative organization responsible for developing accounting standards, is soliciting opinions from all parties on whether to take the lead in formulating an internationally accepted climate information disclosure standard. If a consensus can be reached on including mandatory disclosure of climate information in international information disclosure rules, it will effectively guide and promote the development of global climate finance.

13.3 China's Commitment to Global Climate Cooperation

As a large economy, China plays an important role in promoting the establishment of a global governance system that is fair and reasonable and focuses on win–win cooperation. We believe China will be an important leader along with the US and Europe in the global response to climate change, and that it will also cooperate with "Belt and Road" countries on climate issues in its process of "going global."

13.3.1 From Participant to Leader: China's Active Involvement in Global Climate Cooperation

China was among the first 10 parties to sign the UNFCCC in 1992 and an active participant in global climate cooperation. From the Copenhagen Climate Change Conference to the Paris Climate Change Conference, China has evolved from an important participant to a key leader. China's important contribution to the Paris Agreement is evidenced by its efforts in promoting negotiations, reaching agreements, and efficiently implementing the agreements. After the Paris Climate Change Conference, China utilized its advantages in host diplomacy to promote the signing of a declaration between China and the US at the G20 summit held in September 2016 and significantly accelerated the enforcement of the agreement which took effect in November of that year.[15]

However, with the rapid increase in China's carbon emissions, China's participation in global climate governance also faces challenges. For example, developed countries could take the lead in achieving carbon neutrality, and their accumulated greenhouse gas emissions in a century could be lower than that of China. China needs not only to assume the responsibility of emissions reduction as required by the international community, but also to assume more ethical responsibilities. In addition, China has a limited say in scientific research in international climate cooperation. For example, in the IPCC's Fifth Assessment Report (AR5), the number of Chinese papers cited accounted for merely 2.8%, 1.7% and 1.6% of the total number of papers in climate change science, impact adaptation, and climate mitigation. To some extent, this restricts China's voice in global climate governance.

[15] China's Strategies for Global Climate Governance and International Cooperation, NCSC, September 2020, https://www.efchina.org/Reports-zh/report-lceg-20210207-2-zh.

13.3.2 China is Promoting Global Response to Climate Change Along with Europe and the US

As mentioned earlier, in the process of promoting the adoption and enforcement of the Paris Agreement, China has strengthened cooperation with major powers and vigorously promoted various parties to reach a consensus. The four joint statements issued by China and the US along with the bilateral consensus between China and major developed countries and regions played an important role in ensuring the success of the Paris Climate Change Conference, especially the conclusion, signing, enforcement and implementation of the Paris Agreement.

13.3.2.1 China-EU Climate Cooperation Continues to Advance Steadily

In 2005, China and the EU decided to establish a partnership in the field of climate change. Since then, their relationship has continued to evolve. The release of the *Joint Statement on Climate Change and Clean Energy* in 2018 confirmed that the two parties will continue to strengthen bilateral cooperation in areas such as long-term low greenhouse gas emission development strategies, carbon trading, energy efficiency, and climate-related technologies.[16] In the *China-EU Comprehensive Agreement on Investment*, which was signed in 2020, the two sides reaffirmed their commitment to implementing the Paris Agreement and tackling climate change jointly.

In terms of climate cooperation between China and the US, the two parties explored multiple fields through multiple channels during the Obama administration. Since 2009, the two countries have signed a total of seven bilateral agreements involving climate change cooperation. Leveraging platforms such as the China-US Climate Change Working Group and the China-US Clean Energy Research Center, China and the US established multiple forms of cooperation, such as joint R&D, policy cooperation, and technical assistance. As China-US climate cooperation achieved substantial progress, the fields of cooperation include auto emissions reduction, power systems, carbon capture, utilization, and storage, building and industrial energy efficiency, as well as climate-smart and low-carbon cities.[17] However, with the cooling of China-US relations during the Trump administration, China-US climate cooperation also stalled.

13.3.2.2 Outlook for China-US Climate Cooperation Under Biden Administration

So far, the US remains the country with the largest cumulative emissions since the Industrial Revolution, and one of the countries with the highest per capita emissions,

---

[16] http://www.ncsc.org.cn/SY/gjlhsm/202003/t20200319_769645.shtml.

[17] http://www.ccchina.org.cn/archiver/ccchinacn/UpFile/Files/Default/20160617103440817412.pdf.

while China is currently the world's largest carbon emitter.[18] The full and effective implementation of the Paris Agreement requires cooperation between the two countries.

In terms of domestic development, both China and the US have proposed carbon neutrality goals. In order to consolidate the advantages of the US in low-carbon technologies and industries, President Biden campaigned to have "a carbon-pollution-free power sector" by 2035 and "net zero greenhouse gas emissions" by 2050. He also proposed investing US$2trn in promoting the development of low-carbon industries.[19] Meanwhile, at the end of 2020, the Chinese government put forward the goal of achieving peak carbon emissions by 2030 and carbon neutrality by 2060.

In terms of global cooperation, President Biden announced on the first day of his presidency that the US will return to the Paris Agreement and the US may rely more on the power of its allies, including the EU, the UK, Japan, Australia, and Canada, in the implementation of the Paris Agreement as well as multilateral or bilateral climate diplomacy to reshape relations between large powers. On April 22, 2021, the US held a Leaders' Climate Summit,[20] and over 40 world leaders convened for the meeting, where Canada, the UK, and Japan announced new emissions targets.[21] Through the summit, the US aimed to regain the initiative and leadership in the global climate dialogue.

13.3.3 Climate Cooperation and Building a Green Belt and Road

13.3.3.1 China Actively Promoting a Green Belt and Road

Since the Belt and Road Initiative was put forward in 2013, it has received positive responses from the international community. More than 140 countries around the world have formally signed agreements with China. In 2019, Belt and Road countries accounted for 22% of the world's GDP and about 30.8% of the world's total carbon emissions (Fig. 13.9), mainly because most of these countries are in the stage of rapid industrialization and urbanization.

Since 2013, the Chinese government has issued policy documents to guide firms to adhere to green development and eventually to build a Green Belt and Road.

- **Green infrastructure:** According to data from the American Enterprise Institute for Public Policy Research (AEI), in 1H20, the proportion of renewable energy investment in China's investment in the energy sector of the Belt and

[18] http://www.tanpaifang.com/tanzhonghe/2020/1204/75653_2.html; http://www.tanpaifang.com/tanguwen/2020/0307/68701.html.

[19] http://www.xinhuanet.com/energy/2021-02/02/c_1127052697.htm.

[20] http://forex.cngold.org/fxb/c5476149.htm.

[21] https://news.un.org/zh/story/2021/04/1082682.

2019	GDP	Population	Trade volumn	FDI stock	Total carbon emissions
US	24.4%	4.3%	11.4%	26.0%	14.5%
EU	17.8%	5.8%	30.1%	30.4%	8.0%
China	16.3%	18.2%	10.4%	4.9%	27.9%
India	3.3%	17.8%	2.3%	1.2%	7.2%
BRI Countries	22.0%	43.8%	30.6%	24.8%	30.8%

Fig. 13.9 Carbon emissions of the Belt and Road countries accounted for nearly one-third of the world's total. *Source* World Bank, UNCTAD, CICC Global Institute

Road countries surpassed that of fossil fuel energy for the first time, reaching 58.1%.[22]

- **Green finance cooperation:** In 2017, the People's Bank of China (PBoC) participated in the launch of the Network for Greening the Finance System (NGFS). By the end of April 2019, the number of NGFS members reached 36, including the central banks and regulatory authorities of Thailand, Malaysia, Morocco, and so on.[23] In addition, the Belt and Road Green Investment Principles (GIP) drafted by Chinese and British institutions was signed by 26 large financial institutions from 13 countries and regions.[24]
- **Green technology cooperation:** During the second Belt and Road Forum for International Cooperation in 2019, the Chinese government established the Belt and Road Initiative International Green Development Coalition (BRIGC) jointly with 42 countries to promote the development of Belt and Road green technology cooperation.[25]

By exploring construction of green projects, Chinese companies have accumulated valuable experience and are actively sharing their experience. For example, at the end of 2019, the Mozura wind power project in Montenegro, held by Shanghai Electric Power, was officially put into commercial operation. The project's annual average power generation accounted for 5% of Montenegro's annual electricity consumption volume. It could reduce Montenegro's carbon emissions by 3,000tonnes each year

22 http://www.21jingji.com/2020/12-26/4MMDEzNzlfMTYxNjA4MQ.html.

23 http://kz.mofcom.gov.cn/article/scdy/202008/20200802994698.shtml.

24 http://intl.ce.cn/sjjj/qy/202008/14/t20200814_35527622.shtml.

25 http://news.china.com.cn/txt/2019-04/29/content_74735382.htm.

and should effectively help Montenegro achieve its energy development goals. It should also help the country accelerate the progress toward its sustainable modern energy goals.[26]

13.3.3.2 How to Promote Green Belt and Road?

Looking ahead, in order to develop the Green Belt and Road, we think China needs to explore, innovate, and adapt to different local conditions of Belt and Road countries.

First, we believe China should encourage Belt and Road countries to embrace the idea of green development, adopt a green and low-carbon development model, engage Belt and Road countries in global climate cooperation, and urge them to expand their NDCs.

Second, green finance and green investment could aid the development of the Green Belt and Road. Green infrastructure projects require large investments as they have long duration and limited short-term economic benefits. We think multilateral financial institutions should be at the forefront of green infrastructure investment and green financial support is needed to encourage commercial financial institutions and social capital to engage in green investment.

Third, a Belt and Road national green development information exchange platform needs to be established, to provide assistance and support within China's capacity in areas such as green energy, green technology, green finance, and green manufacturing.

Lastly, we think the continued decline in the costs of renewable energy will gradually create conditions for domestic industries to "go global". Given China's experience in renewable energy equipment, technology, and management, we believe it can guide and encourage renewable energy companies to actively participate in the construction of the Belt and Road.

[26] Belt and Road Green Development Report: Case Studies 2020, BRIGC, http://www.sasac.gov.cn/n2588025/n2588139/c11632202/content.html.