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National Center for Climate Change Strategy and International Cooperation (NCSC)

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Pursuing an Innovative Development Pathway: Understanding China's NDC

Contents

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Key Findings

ON 30 JUNE 2015, THE CHINESE GOVERNMENT SUBMITTED ITS NATIONALLY DETERMINED CONTRIBUTION (NDC), DETAILING ITS COMMITMENT TO CLIMATE CHANGE MITIGATION AND ADAPTATION FOR THE POST-2020 PERIOD.

Highlights of the NDC include specific goals to be completed by 2030 such as:

- To achieve peak carbon dioxide emissions by approximately 2030, or sooner as best efforts allow;
- To lower carbon dioxide emissions per unit of GDP by 60% to 65% from 2005 levels;
- To increase the share of non-fossil fuels in the primary energy mix to approximately 20%;
- To increase the volume of forest stock by approximately 4.5 billion cubic meters over 2005 levels; and
- To continue to proactively adapt to climate change through enhanced mechanisms and capacities. This includes the effective management of climate change risks in sectors such as agriculture, forestry, and water resources, and urban, coastal, and ecologically vulnerable areas. Effort will also be taken to improve early warning and emergency response systems, and disaster prevention and reduction mechanisms.

- **China is seeking to shift to a 'new normal', a transition that it intends will be powered by an 'innovative development pathway'.** China's traditional input-heavy growth model is no longer sustainable. Constrained by limited resources and environmental pressures, China now risks falling into the 'middle-income trap'. The country is therefore aiming to shift to a 'new normal', focusing on the transformation of the industrial sector and reorientation towards domestic demand. It plans that this will be delivered by an innovative development pathway which shifts the drivers of growth away from increasing the quantity of inputs towards improving their efficiency, supported by institutions facilitating this growth in productivity. This new approach hopes to reduce dependence on energy, resources, and environmental inputs, and instead cultivates new growth points that allow for the adoption of a low-carbon, efficiency-focused development pathway.
- **China is integrating the innovative development pathway into all of its strategic planning.** Five development concepts characterized by "innovation," "coordination," "green," "openness" and "sharing" have been clearly identified in China's 13th Five-Year Plan (FYP). China is committed to creating the technological, financial, and other conditions necessary to achieve this fundamentally different model of development.
- **China's nationally determined contribution (NDC) can be a critical vehicle in driving the shift onto the innovative development pathway and towards the 'new normal'.** The modelling done in this report shows that meeting the NDC targets is feasible when appropriate

measures to both decarbonize energy and reduce the energy intensity of GDP are taken. If successful, the country's accelerated action on climate change will facilitate the decoupling of economic growth from carbon emissions and could lead to a fundamental restructuring in the country's energy sector.

- **In achieving China's NDC, improving energy efficiency, increasing the electrification rate of end-use sectors, reducing energy service demand by structural change and sustainable consumption, as well as decarbonization of the energy system by shifting from coal towards gas and electricity are all expected to play key roles.** Carbon pricing, especially the national emission trading system, will have an important role to play in delivering these changes.

- **China faces challenges in achieving its NDC, but there are also many co-benefits.** Among other challenges, the country will face challenges in overcoming large up-front costs in retiring carbon-intensive infrastructure and financing low-carbon projects, whilst managing the political economy challenges of decarbonization. Overcoming these challenges can be made easier by a greater role for economic incentives and market-based measures, implemented in conducive market structures. At the same time, the potential co-benefits of meeting the NDC are significant and intersect with other key development objectives such as energy security and health. Some of the co-benefits could directly address challenges and could outweigh the disadvantages.

- **China's NDC can make an important contribution in supporting international progress towards the 2°C goal.** As well as helping China make the transition to the innovative development pathway, successful implementation of the NDC can foster the enabling conditions in the 2020s that will be essential for enhanced mitigation beyond 2030. The analysis shows that China's NDC, and the subsequent emission reductions it will allow, is consistent with global emissions pathways that meet the 2°C goal.

- **Successfully moving onto the innovative development pathway can allow China to peak its emissions at a lower GDP per capita and at an earlier stage of development than any developed country has done.** It would lead to an emissions per capita peaking level that is comparable to that which the EU achieved. While this partly reflects that the country has been able to benefit from the increased global availability of low-carbon technologies, it also suggests that China's innovative development pathway constitutes a new example of development that other developing countries could follow.

- **Although challenges and uncertainties remain, China is on track to achieve its NDC goals and has significant potential to further enhance its action.** China's 13th Five-Year Plan looks set to deliver a 50% reduction of China's CO_2 emission intensity by 2020 compared to the level of 2005, a move which could serve as a basis for further action.

- **China's NDC can also be the basis for the country to develop its long-term, mid-century low emission development strategy.** This strategy will need to integrate both long-term and short-term thinking and the interlinkages between emission reductions and other development goals, especially social, economic and environmental goals. The key issues to be addressed next are to develop an integrated cost-benefit analysis, so as to develop and coordinate a well-designed policy framework, as well as undertaking more analysis of the impact of recent economic trends on NDC attainment and China's role in the global and regional context of achieving the global long-term target.

Achieving China's 'New Normal' through the 'Innovative Development Pathway'

SUMMARY

China's impressive double-digit economic growth in recent decades has lifted more than 600 million people out of poverty.

Continued reliance on the existing growth model is unlikely to be as successful in the future. This growth model has contributed to increased inequality, environmental degradation and could lead to the 'middle-income trap'.

China is now seeking to progress towards a 'new normal'. This new normal will be achieved through an 'innovative development pathway' that aims to provide cleaner, consistent and better quality growth. Both the new normal and innovative development pathways are compatible with China's NDC and eventual decarbonization.

The Constraints to China's Current Growth Model

China's unparalleled economic growth over the past three decades has elevated it to middle-income status and lifted hundreds of millions out of poverty. China's rapid industrialization and urbanization has successfully taken it to a higher level of development. Since initiating market reforms in the late 1970s, China has achieved an average annual growth rate of 10%. According to the Chinese National Bureau of Statistics (NBS, 2015), by 2011 China had reached upper-middle-income status with a per capita gross national income of almost US$5,000. China's total economic output is now the second largest in the world and its GDP per capita has increased to around US$7,600. This rapid growth has enabled it to cut its poverty rate from 84% in 1981 to 13% in 2008, lifting 600 million people out of poverty.

There has been significant progress, but continued development remains essential. Despite China's rapid rate of development, it ranked only 77th by nominal GDP per person and 89th using purchasing power parity (PPP) rates in 2014 (IMF). The number of Chinese living in poverty remains high: around 40 million rural poor still live below the official Chinese poverty line (1,067 RMB per year) while the number is as high as 395 million when measured against a standard of US$2 per day (in PPP) (NBS, 2015). China's continued and foremost strategic priorities are to focus on poverty alleviation, increase average income, bolster social security, expand coverage of public services and generally raise the standard of living.

Achieving development objectives through China's traditional input-heavy growth model is unsustainable. The increased use of inputs (labor, capital, energy, land, water, mineral products, etc.) has made a major contribution to China's rapid economic growth over three decades. These inputs have been directed towards an economic structure focused on exports and investment (49% of China's GDP in 2014) and manufacturing (43% of GDP in 2014). The continued viability of this growth model is increasingly being questioned due to rising private debt, risks of financial instability, manufacturing overcapacity, and a large base of lower-value manufacturing which is at an increasing risk of losing competitiveness due to rapidly rising labor costs (Fulin, 2015; IMF, 2014).

Resource constraints and environmental pressures compound this challenge. There are limits to national and global resources that are already affecting China's economic prospects. High-carbon sources of energy are a prime example. China's increasing dependence on energy imports brings energy security challenges and exposure to international price volatility. Moreover, atmospheric carbon space is becoming a scarce strategic resource that needs to be factored into future development. In 2014, China's CO_2 emissions from fossil-fuel combustion and cement production reached 105 $GtCO_2$, the equivalent of almost 30% of the world's total emissions from these sources (PBL, 2015). Likewise, the environmental and economic problems of air pollution are becoming increasingly clear. Coal-fired power stations and heavy industries are emitting large amounts of sulphur dioxide (SO^2), nitrogen oxides, particulate matter (PM2.5) and smoke dust, threatening public health and labor productivity. Of the 338 cities at prefectural level or above, 265 do not consistently meet air quality standards for PM2.5, with the average proportion of days where these standards are exceeded being 23.3% (MEP, 2016).

To avoid the long-term socioeconomic costs of environmental pollution China is seeking to change. It intends to shift its economy to a more advanced industrial development with lower carbon emissions and a higher allocation of national resources directed towards innovation. If this transition fails to materialize in a timely way, China is likely to fall into the 'middle-income trap', seriously jeopardizing the realization of 'the two 100s goals'.[1] The 'middle-income' trap is a theory based from empirical observations of middle-income countries such as Brazil and Turkey (Gill et al, 2007). While explanations differ, it suggests that once countries reach a middle-income stage their economic growth slows substantially and they fail to transition into a high-income country. While the high-speed growth of its past may be unsustainable, China must find a way to avoid the middle-income trap and instead achieve more efficient, moderate growth over the long term.

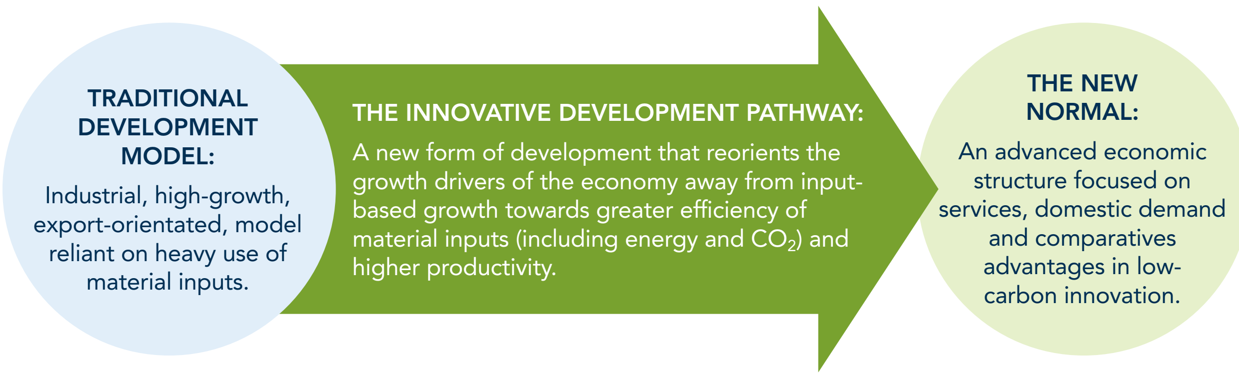
The 'New Normal' and the 'Innovative Development Pathway'

Given the challenges identified above, China is seeking to shift to a 'new normal', focusing on higher-quality growth. As the largest emerging country and largest producer of greenhouse gas emissions, China has the ambition and responsibility to change its model of development. This will allow it to upgrade its growth model to a 'new normal' in order to both mitigate some of the effects of global climate change and to respond to domestic development constraints resulting from resource use and environmental issues. The 'new normal' envisages a reformed economic state that will have medium, rather than high-speed, growth. The growth will be higher quality, mainly driven by innovationThe economy will have a greater reliance on domestic consumption, services and higher value-added manufacturing, including energy efficiency and low carbon manufacturing industries. Domestic demand is expected to become a key pillar of economic activity as export demand decreases in relative terms due to rising labor costs. At the same time, it envisages that inefficient and overcapacity energy plants will be phased out. In short, the new normal seeks to shift the economy in a way that is markedly different to its current structure and that is more compatible with low carbon and the globally adopted Sustainable Development Goals.

1 Xi Jinping's Chinese Dream is described as achieving the 'Two 100s': the material goal of China becoming a 'moderately well-off society' by 2021, the centenary of the emergence of the Chinese Communist Party; and the

The innovative development pathway is the process and restructuring required to reach the new normal. The innovative development pathway aims to create low-carbon and green growth that brings about the changes in economic activity, energy production, consumption and land-use change needed to reach the new normal. In practice, the plans involve a higher share of nonfossil fuel energy sources in energy generation and consumption, as well as increasing energy productivity and reduced dependence on energy, resources and environmental inputs. The relationship between the traditional development model, the innovative development pathway and the new normal is shown in Figure 1.1

FIGURE 1.1. An Overview of the Transition Towards the New Normal



The concept of the innovative development pathway focuses on all aspects of economic development. An economy's development path is determined and influenced by a wide range of factors such as the drivers of economic growth (input growth versus efficiency); choice of economic structure; and industrial organization, technology, finance, capability, infrastructure, political institutions, and social governance. The range of potential development pathways are diverse. The concept of the innovative development path has constructive policy implications relating to all of these factors. It focuses on substantial and specific actions for both developed and developing countries within a general framework of sustainable development with an aim to achieve economic growth through improving factor efficiencies and minimizing reliance on the expansion of factor input. In this way, it can maximize the output efficiency per unit of input (including energy and CO_2 input). This change in the drivers of growth will likely require greater investment in a broad diversified portfolio of national assets, including natural capital, knowledge capital and institutions.

China intends to integrate the innovative development pathway into all of its strategic planning. Five development concepts characterized by "innovation," "coordination," "green," "openness" and "sharing" have been clearly raised in China's 13th Five-Year Plan (FYP). China is committed to creating the technological, financial, and other conditions necessary to achieve this different model of development. This will build on issues that China has already started to introduce through its five-year planning process, especially the integration of energy consumption, energy efficiency and environmental implications (see Annex A).

The Purpose of This Report: Exploring the Links Between the NDC and the Innovative Development Pathway and the New Normal

Both the new normal and innovative development pathway are inherently connected to low-carbon growth and sustainable development; the purpose of this report is to explore these links in detail. Based on an understanding of the likely trajectory of emissions under a business as usual trajectory and the mitigation potential in different sectors, the report sets out a scenario through which China might meet its NDC. It explores what emission reductions might be required from which sectors and the contribution that different drivers of emission reduction might play in realizing the NDC. This allows the report to 'paint a picture' of how China's economy will likely need to evolve in order to meet the NDC and therefore to understand the close alignment between the structural change needed to realize the NDC and the innovative development pathway and China's ambitions for the new normal. The focus is on the energy CO_2 aspects of China's NDC. While the NDC's commitments surrounding both reforestation and increased climate resilience are key elements of China's NDC, CO_2 emissions from energy are the single biggest component of China's overall emissions profile—accounting for [80%] of its emissions—and it is the country's approach to dealing with these emissions where the overlaps with the innovative development pathway and new normal are most pronounced.

By providing greater understanding of what China's NDC will require, the report can begin the process of identifying key NDC implementation challenges—but this report only begins this process and further work on developing a strategy for implementing the NDC may be valuable. Through providing a more detailed understanding of what structural changes are needed to the economy, this report highlights some of the attractions and co-benefits available to China through successful implementation of its NDC. However, it also exposes some of the tensions and difficulties that the country will likely face in order to achieve these necessary structural changes. The report also shows how these tensions are reflected in some contradictory policy settings; for example, there is policy support for the financing and construction of wind power plants, but the output from these plants is subsequently heavily curtailed in order to not undermine coal-fired power generation. To address these tensions, and assist with NDC implementation, it could be valuable to develop an implementation strategy for the NDC. This implementation strategy could focus on both the policy and the institutional settings that would support the NDC and the innovative development pathway and hence address the challenges identified in this report. This report considers some of the analytical tools that might support the delivery of this implementation strategy.

By proving deeper understanding of what successful implementation of the NDC might look like, the analysis is also intended to support researchers in evaluating China's NDC. Some evaluation is provided in this report. For instance, the detailed development of the NDC scenario in this report facilitates an international and historical comparison of the emissions profile of the Chinese economy—and some of its key sectors. Similarly, by understanding how China might meet the 2030 'peaking' goal of its NDC—and, critically, at what level of emissions—the report can assess whether China's NDC is consistent with the global goal of keeping global temperature increases below 2°C. However, much more analysis reviewing and evaluating China's NDC is possible and we hope that the NDC implementation scenario and associated analysis in this report can support researchers in these endeavors.

The remainder of the report is structured as follows:

- Chapter 2 introduces China's NDC and identifies a business as usual trajectory of emissions, the mitigation potential that might be available in different sectors under this trajectory. From this, it develops a modelling scenario which explores how China's NDC might be met and the implications that this could have on China's economy and the pursuit of the new normal.
- Chapter 3 explores the co-benefits that could be realized from successful implementation of the NDC, but also identifies some of the challenges and uncertainties.
- Chapter 4 provides an international perspective on China's NDC.The annexes provide more information on China's pre-NDC emission reduction efforts, key socioeconomic and environmental trends underpinning the analysis, more detail on the international comparison exercise and more information on the PECE model used for some of the work.

China's NDC as a Vehicle for Achieving the Innovative Development Pathway

SUMMARY

China's NDC is planned to be the key vehicle for moving onto the innovative development pathway and transitioning to the new normal.

Given continued economic growth, China's NDC and peak emissions by 2030 will only be achieved by accelerating structural change and reducing energy and carbon intensity.

There are a range of opportunities to reduce energy and carbon intensity across the power, industry, buildings and transport sectors.

A series of specific measures will need to be put into place to achieve this transformation. These include regional and national measures for supporting science and technology, developing economic incentives and behavioural change.

Even with this ambitious agenda, there will be a need for stronger emissions reductions beyond 2030 to achieve the global goal to keep temperature increases below 2°C. China's NDC should help the country in establishing enabling conditions that will be essential for deeper mitigation beyond 2030.

China appears on track to achieve its NDC goals and has significant potential to further enhance its action.

China's Nationally Determined Contribution (NDC)

On 30 June 2015, the Chinese Government submitted its (Intended) Nationally Determined Contribution (NDC)[2], detailing its commitment to climate change mitigation and adaptation for the post-2020 period. Highlights of the NDC include specific goals such as to[3]:

- achieve peak CO_2 emissions by approximately 2030, or sooner as best efforts allow;
- lower CO_2 emissions per unit of GDP by 60–65% by 2030 from 2005 levels;
- increase the share of nonfossil fuels in the primary energy mix to approximately 20% by 2030;
- increase the volume of forest stock by approximately 4.5 billion cubic meters over 2005 levels by 2030; and
- continue to proactively adapt to climate change through:
- enhanced mechanism- and capacity-building,
- the effective management of climate change risks in sectors such as agriculture, forestry, and water resources, and in regions including urban, coastal, and ecologically vulnerable areas,

2 When originally submitted, it was its Intended Nationally Determined Contribution (INDC); it has now become its Nationally Determined Contribution (NDC) and is referred to as such throughout this report.

3 Enhanced Actions on Climate Change: China's Intended Nationally Determined Contributions, 2015

- improved early warning and emergency response systems and disaster prevention and mitigation mechanisms.

The NDC also contains a range of implementation measures and policies designed to manage existing climate change risk and fulfil the NDC's mandate across mitigation, adaptation, financing, technology development and transfer, capacity building, and transparency. It also calls for a broadening and deepening of south-south cooperation on climate change, including the establishment of a fund for such cooperation. As explained in the introduction, while the NDC is a comprehensive document that focuses on all aspects of China's climate response, the focus of this report is on the contributions related to energy CO_2 emissions as the major source of China's GHG emissions.

This chapter analyses China's baseline 'business as usual' (BAU) as well as the mitigation potential of a range of difference sectors before examining a scenario for implementing China's NDC. The technical abatement discussion provides new analysis of the abatement potential available in China and how this is split both across sectors and between controlling service demand, energy efficiency, energy structure optimization and the use of CCUS technologies. The NDC analysis then provides a new analysis showing how this technical abatement potential can be exploited and the implications it would be have for structure of the Chinese economy and its energy and carbon intensity. The analysis suggests that China is capable of meeting and potentially exceeding its NDC targets.

China's Current Trajectory and BAU Scenario

China's NDC constitutes the first time a specific timeline for setting an absolute target on controlling CO_2 emissions has been set. Given the NDC and the shift in China's economic and environmental position in recent years, China needs to build new and updated scenarios. One such baseline scenario is provided in the discussion below, to serve as a reference for evaluating China's additional efforts in combating climate change after 2014.

The BAU scenario presented here takes account of both likely trends in economic growth as well as existing policies to reduce emissions (See Annex A). Considering China's current stage of industrialization and urbanization, its energy use and energy-related CO_2 emissions will likely increase, in the near term, alongside the country's economic and social development. At the same time, China has set a number of targets since 2010 relating to GHG emissions control, and has adopted plans and policies promoting low-carbon development. These cover the energy, building, transportation, industry and forestry sectors. The core contents of these targets and policies involve raising requirements for energy efficiency, setting energy-consumption caps, energy and industrial structure optimization, and reducing the carbon intensity of energy. However, under the BAU scenario, most current policies/targets addressing climate change are assumed to expire around 2020, and no extra policies or emission-control targets are implemented after 2014. This means that variables such as carbon intensity (carbon emissions per unit of GDP) and use of nonfossil fuels continue to improve after 2020, but at a lower rate, as the associated policy and economic incentives are assumed to be weaker.

The BAU scenario rests on a number of core assumptions. By reviewing a range of relevant expert judgments and research, it is anticipated that the annual average growth rate of GDP per capita will be 5.0% over the period 2010–50, with a gradual decline of growth rates from 6.6% over the period 2015–20 to 3.2% over the period 2040–50. Population will continue to grow and is projected to peak at around 1,470 million by 2030, before gradually declining to 1,410 million by 2050. As China enters the latter stage of industrialization in the near future, urbanization is expected to continue and become the main impetus for a rise in living standards. It is assumed that the urbanization rate of China will rise continuously from its current rate of 56.1% in 2015 to 76% by 2050. In turn, this will push up energy use and carbon emissions. Table 2.1 provides an overview of the growth in development indicators (including urbanisation) up to 2050.

TABLE 2.1. Development Indicators in China Under BAU Scenario

	2010	2013	2014	2015	2016
Population (millions)	1,341	1,408	1,467	1,442	1,409
GDP per capita ($ per capita, 2010 price)	4,505	8,639	14,026	21,539	29,984
Urbanization rate	50%	62%	68%	73%	76%

China's BAU energy consumption and carbon emissions scenarios are presented in Figures 2.1 and 2.2, alongside a comparison with BAU scenarios from earlier models. In the BAU scenario, China's carbon emissions are expected to reach 11.5, 14.8 and 15.3 GtCO_2 in 2020, 2030, and 2050, respectively. In this scenario, in 2020 China's carbon emissions per unit of GDP is 45% lower than in 2005, successfully meeting China's Copenhagen pledge. In 2030, carbon intensity is 57% lower than in 2005, which is a smaller reduction than the carbon intensity target set in China's NDC. Emissions peak by around 2040, not 2030 as specified in the NDC, at which point annual per-capita carbon emissions are 11.4 tCO_2. They then fall to 11.3 tCO_2 by 2050. Energy consumption is estimated to rise from 2.5 Gtoe in 2010 to 3.7, 5.0 and 5.7 Gtoe in 2020, 2030 and 2050, respectively. Nonfossil fuel energy use gradually increases with its share in primary energy consumption growing from 9.4% in 2010 to 12.6%, 14.0% and 20.0% in 2020, 2030 and 2050. The 2030 figures fall short of the target set out in China's NDC (14% compared to 20%).

FIGURE 2.1. Primary Energy Consumption in BAU Scenarios in Various Studies

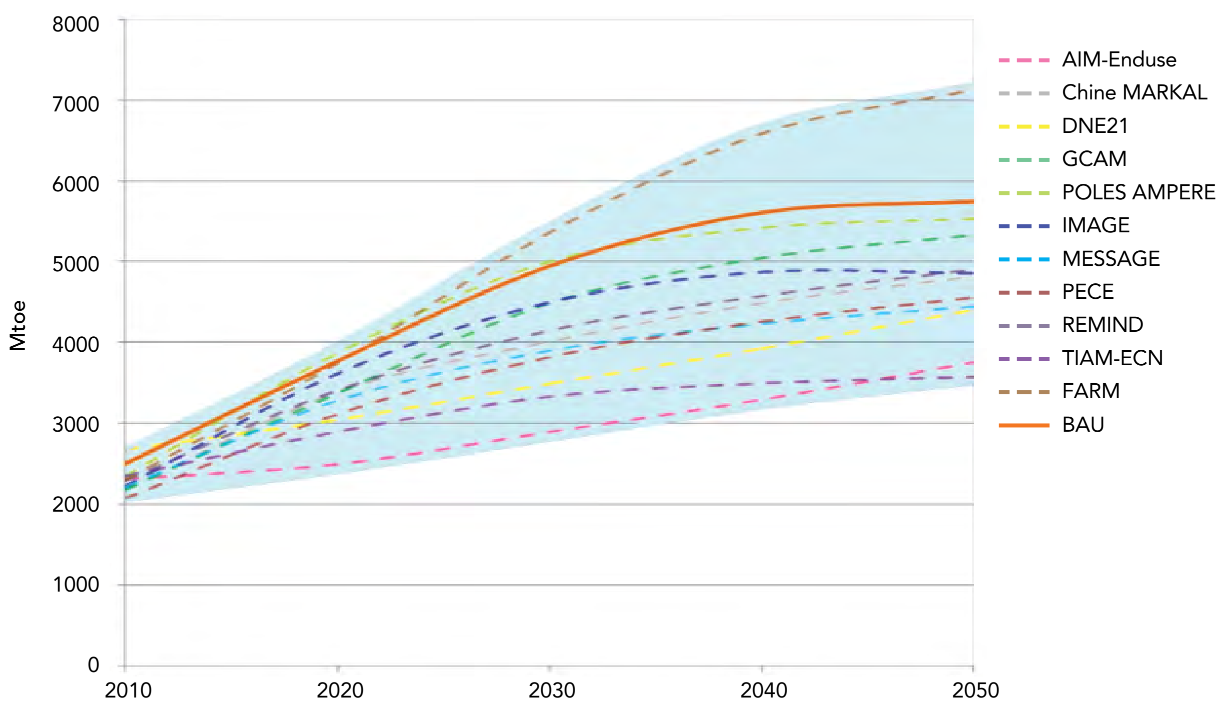
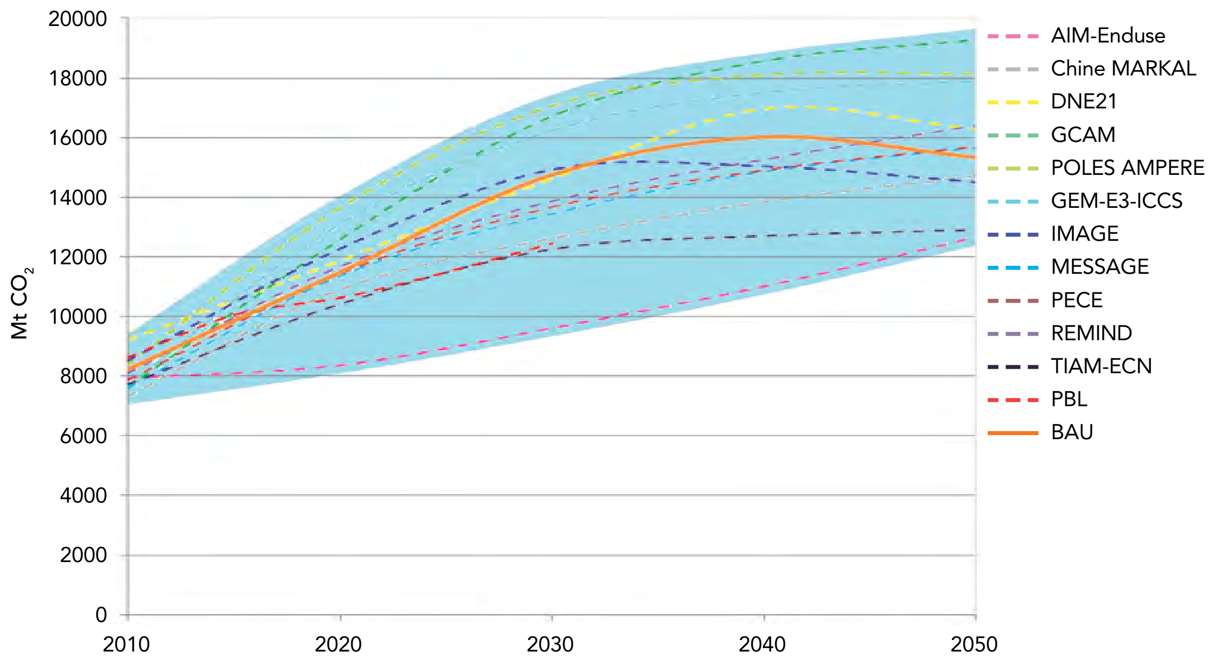


FIGURE 2.2. Carbon Emissions in BAU Scenarios



The comparison with other BAU scenarios shows that the BAU scenario in this analysis is consistent with, but towards the higher end of, those previously published. In recent years, many institutes have conducted studies on BAU scenarios in China.[4] In conjunction with the Strategy Analysis on low-Carbon in China (SACC) model,[5] these scenarios have informed the BAU scenario used in this analysis. Although the definitions and assumptions of these scenarios differ substantially, it can be seen that the results follow a broadly similar trajectory. It should be noted that the energy consumption data for the base year of 2010 has been adjusted according to the most recently released data from the *China Energy Statistical Yearbook 2015*. This provides part of the explanation of why the projections of future energy demand and carbon emissions in the BAU scenario in this report are generally higher than those from other research institutes.

The Carbon Mitigation Potential of Each Sector

This section analyzes the emission reduction opportunities in each sector and the effects these could have on the country's energy-related carbon emissions. To further increase mitigation efforts, in addition to more proactive management of energy intensity and carbon intensity, China is expected to implement caps on fossil fuel consumption and carbon emissions in the 13th FYP period. Policy support for nonfossil energy development will also likely be enhanced. The section considers the sectoral abatement opportunities that these policies, and those beyond 2020, might tap to deviate emissions from the business as usual trajectory. Understanding this techno-economic abatement potential (which is explored by sector in sections 2.31–2.34 and then explored in aggregate in section 2.4) is a vital input into the NDC implementation scenario set out in section 2.5.

4 From project specific databases of the nine model inter-comparison projects that are included in the IPCC AR5 database.

5 The SACC model is a "bottom-up" analysis model developed by NCSC with 10-year intervals extending from 2010 to 2050. It is an energy technology analysis module that uses an accounting method for end-use sectors (including industry, transport and building sectors) and a least-cost optimization method for the power generation sector. In the SACC model, many key factors such as future trend of service demands, efficiency improvement, and fuel substitution are taken into consideration through literature reviews and expert consultation.

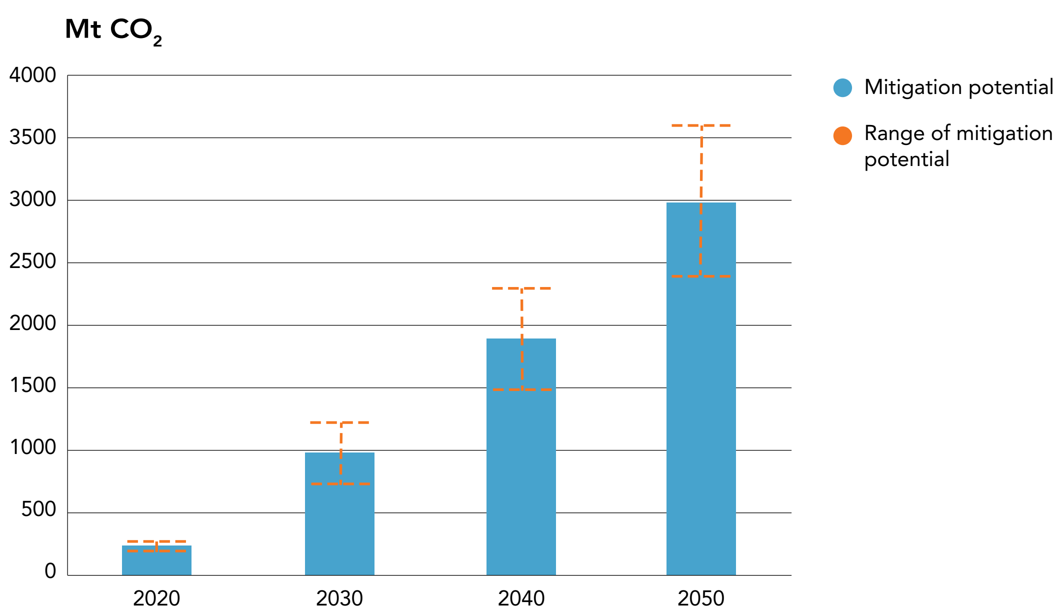
The Power Sector

In the power sector, a range of preferential policies for nonfossil fuel development are expected to be continued to be granted in the short- to medium-term (before 2030). This includes research and development support, subsidies, and priority grid access. This should encourage commercialization, improve efficiencies, and further guarantee operational stability. Continued efforts to rationalize the electricity price mechanism are expected to further promote the sustainable development of the power sector. Efforts will be taken to optimize the price relationship between coal, gas and electricity, while environmental externalities are expected to be increasingly reflected in prices. Under these measures, nonfossil fuel power generation might increase 612–987 TWh and 1,592–2,451 TWh in 2030 and 2050 respectively. The proportion of nonfossil fuel power generation can increase by 7–11 and 19–25 pps compared with the BAU scenario.

Emissions reductions can also be sourced from thermal generation. Outdated coal-fired power plants are expected to be gradually phased out and more efficient ultra-supercritical (USC), supercritical (SC), integrated gasification combined cycle (IGCC) and combined cycle gas turbines (CCGT) technologies will be encouraged. This might increase the generation efficiency of thermal power plants by 16–18% in 2050 compared with 2010, almost 3–5 pps higher than in the BAU scenario. Carbon capture utilisation and storage (CCUS) technologies can also be more heavily deployed, with 15–33% of coal-fired power generation potentially equipped with CCUS by 2050. The total captured CO_2 will be 6–12 Gt to 12–30 pps higher than under BAU.

Combining these efforts, the carbon mitigation potential that can be achieved in the power generation sector could be 0.24 Gt, 0.99 Gt and 3 $GtCO_2$ in 2020, 2030 and 2050, respectively. If even greater efforts are made, the mitigation potential could increase to 0.28, 1.24 and 3.61 $GtCO_2$ in 2020, 2030 and 2050, an increase of a further 16–25%. These estimates are depicted below in Figure 2.3.

FIGURE 2.3. The Carbon-Mitigation Potential in the Power Sector



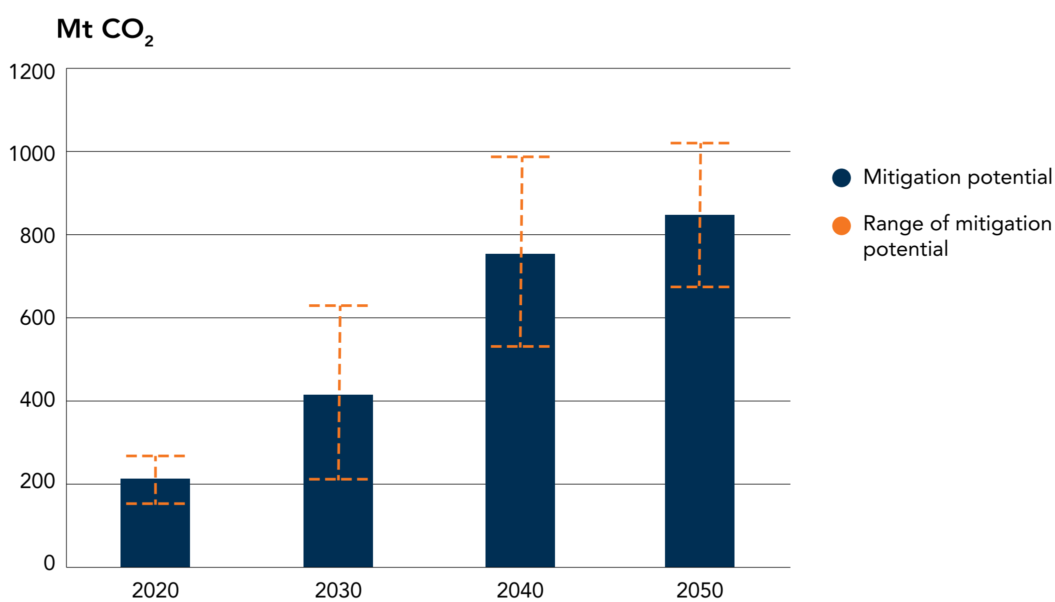
The Industrial Sector

A wide range of measures can also be pursued in the industrial sector. Major measures include the transformation of the economy and the development of tertiary industry; controlling overcapacity of major energy-intensive industrial outputs; eliminating backward production capacity (and prohibiting new industrial capacity until an equivalent amount of inefficient capacity has been shut down); and accelerating industrial restructuring and upgrading. Key expected impacts include:

- The share of secondary industry in GDP is expected to decrease gradually to 0.6–1.3 pps, 0.5–1.5 pps and 1–2 pps less than in the BAU scenario in 2020, 2030 and 2050, respectively. This is close to that of Japan and Germany in the early 1990s and the world average level in the mid-1980s.
- Through encouraging the enhancement of energy-saving techniques, implementing technical transformation, research and development, and further promoting energy efficiency, the energy consumption per unit of output in the main industrial sectors could be reduced by 4–8 pps in 2050 compared with the BAU scenario.
- With enhanced efforts to move from coal-fired boilers to gas-fired boilers, and greater use of electricity, the share of coal in the industrial energy mix could be reduced by 3–10 pps, while the share of natural gas and electricity could increase by 3–7 pps and 1–7 pps compared with BAU in 2050.
- In addition, by accelerating technology development, promoting demonstration projects, improving the regulatory framework and providing a substantial price signal, commercial CCUS applications in industry can accelerate from 2030, potentially capturing an additional 140–160 Mt of CO_2 compared with the BAU scenario in 2050.

Combining all these efforts, the carbon-mitigation potential in the industrial sector could be 0.21, 0.42 and 0.85 $GtCO_2$ in 2020, 2030 and 2050, respectively. With more effort, the mitigation potential might be increased to 0.27 Gt, 0.63 Gt and 1.03 $GtCO_2$ in 2020, 2030 and 2050, an increase of 20–50%. These estimates are illustrated in Figure 2.4.

FIGURE 2.4. Carbon-Mitigation Potential in the Industry Sector



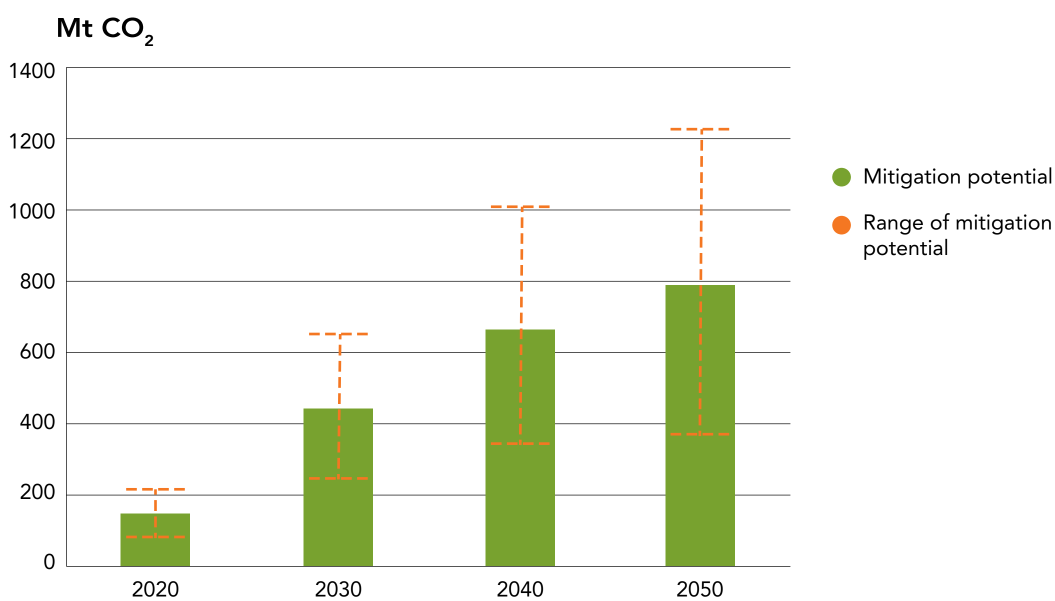
The Building Sector

For the building sector, both administrative and economic measures are needed to restrict the rapid growth of energy consumption and CO_2 emissions. Expected measures and policies include the following:

- Administrative measures including improved urban planning and restrictions on the unreasonable mass demolition of existing buildings. Economic measures might include taxes on residential buildings and schemes to enhance awareness of the benefits of low-carbon technologies. Together these measures might restrict the growth of per-capita area of public buildings and per-capita living area to 3–7 m^2 and 2–3 m^2 smaller than under BAU in 2050. This is similar to levels in major EU member states (IEA, 2015).
- With better financing and supporting policies, low-carbon technologies such as energy-efficient electrical appliances and heating networks, waste-heating generation, and distributed renewables are expected to also reach the large-scale commercialization stage. Compared with BAU, the energy efficiency of the northern urban area heating supply might further increase by 10–15% in 2050, with combined heat and power (CHP) generation and waste heat serving as the major sources of heat supply.
- As the most convenient and often the cleanest energy type, electricity will dominate final energy use in the building sector with coal use curtailed to the extent that its share in the energy consumption of the sector might drop to 10–16% by 2050, 1–7 pps lower than under BAU.

Combining all these efforts, the carbon-mitigation potential in the building sector is estimated to be 0.15 Gt, 0.45 Gt and 0.79 Gt CO_2 in 2020, 2030 and 2050, respectively. With greater efforts, the mitigation potential could be increased to 0.22 Gt, 0.66 Gt and 1.23 $GtCO_2$ in 2020, 2030 and 2050, an increase of 46–55%. An overview of these estimates is shown in Figure 2.5.

FIGURE 2.5. Carbon-Mitigation Potential in the Building Sector



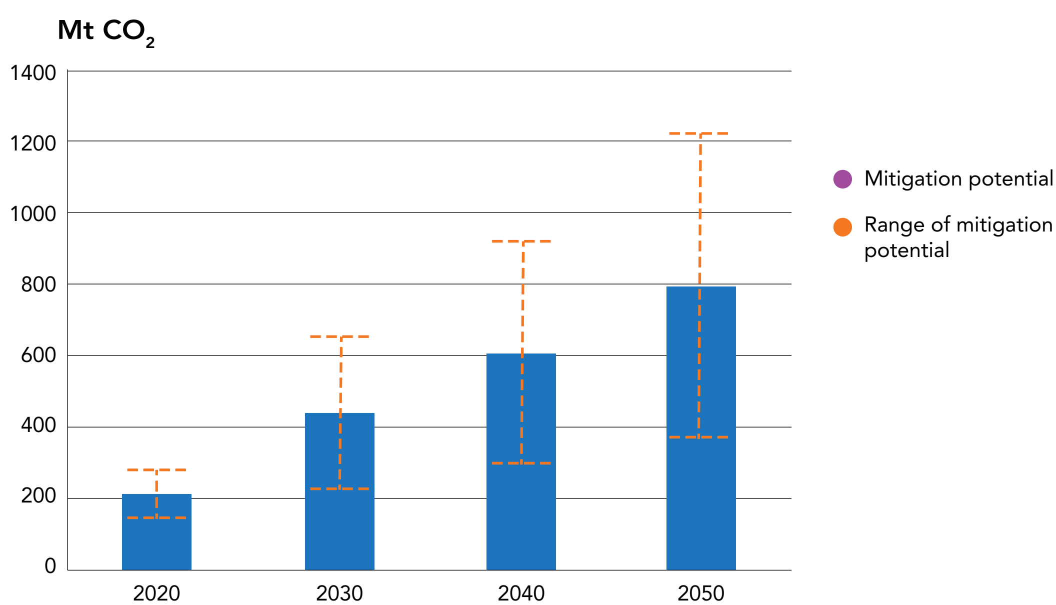
The Transport Sector

In the transportation sector, restricting the increase in demand for transportation services, improving energy efficiency, and optimizing the energy-consumption structure are the key measures expected to realize the sector's mitigation potential. The expected measures include the following:

- First, by implementing policies to increase the capacity of public transport (such as mass rapid transit (MRT) and bus rapid transit (BRT)), and enhancing the implementation of transit-oriented development (TOD) in urban construction planning, the growth of freight and passenger turnover should be slowed. Passenger and freight turnover might reach 27–30 trillion person-kilometers and 58–61 trillion tonne-kilometres respectively in 2050, a reduction of 6–15 and 6–12 pps compared with the BAU scenario. Vehicle ownership per 1,000 persons is expected to increase quickly as a result of rapid urbanization, but could plateau at 350–380 in 2050—lower than the level of 420 in the BAU scenario and equivalent to around half the current level in the United States (US).
- Second, energy efficiency would be increased by the use of intelligent transport management, stricter fuel economy standards, and improved gasoline quality. Vehicle fuel economy could be 8–40% higher in 2050 than under the BAU.
- Third, strengthening research and development, promoting subsidies for clean energy vehicles and launching incentive policies and measures to improve the electrification rate of the vehicle fleet can help to reduce emissions. The combined share of fuel cell vehicles (FCV) and electrically propelled vehicles (EPV) in the total light-duty vehicle fleet might be 3–22 pps higher than under BAU in 2050. The energy structure can be also optimized by technological breakthroughs and innovation in electric vehicle and biofuel replacement, which might increase the electrification rate of the transport sector by 8.5–14% in 2050, nearly 0.5–6 pps higher than in the BAU scenario.

Collectively, these efforts could result in a mitigation potential in the transportation sector of 0.22 Gt, 0.44 Gt and 0.79 GtCO_2 in 2020, 2030 and 2050, respectively. With greater effort, this could be increased to 0.28 Gt, 0.65 Gt and 1.22 GtCO_2 in 2020, 2030 and 2050—an increase of 30–54%. These estimates are shown in Figure 2.6.

FIGURE 2.6. Carbon-Mitigation Potential in the Transportation Sector



Total Mitigation Potential and Contribution Factors Analysis

This section aggregates the overall emission reduction potential from the sectoral analyses above to help identify the total emission reductions available.

Overall Mitigation Potential

The combination of the enhanced mitigation efforts across different sectors suggests a mean carbon-mitigation potential value of 0.85 $GtCO_2$ in 2020, 2.3 $GtCO_2$ in 2030, and 5.4 $GtCO_2$ in 2050 (see Figure 2.7). Under this scenario, carbon intensity would fall by 64% between 2005 and 2030, approaching the upper bound of the carbon intensity target set in China's NDC. Carbon emissions would peak at around 12.5Gt by 2030, consistent with the carbon emissions peaking year target set in the NDC. Primary energy consumption would also decrease significantly compared with the BAU scenario—by 181, 435 and 844 Mtoe in 2020, 2030, and 2050, respectively, as shown in Figure 2.8. The share of nonfossil fuel energy in total primary energy consumption would increase to 14.5%, 19% and 31% in 2020, 2030 and 2050, the 2030 figure being lower than the 20% target in the NDC.

More efforts are needed in order to fully tap the mitigation potential and fully achieve the targets set in China's NDC, especially the nonfossil fuel energy development target. This includes enhancing infrastructure for long-distance transmission and improving electricity grid stability. By doing so, the share of nonfossil fuels in total primary energy consumption could rise to 20.5% in 2030 and 35% in 2050. Combined with other measures in both power sector and end-use sectors, under this augmented scenario, carbon intensity would fall by 67% between 2005 and 2030 which is higher than the 65% target in the NDC, and emissions can peak earlier than 2030 with a peaking value lower than 12 $GtCO_2$ (indicated as the lower bound of mitigation range).

FIGURE 2.7. Carbon-Mitigation Potential in China from 2020 to 2050

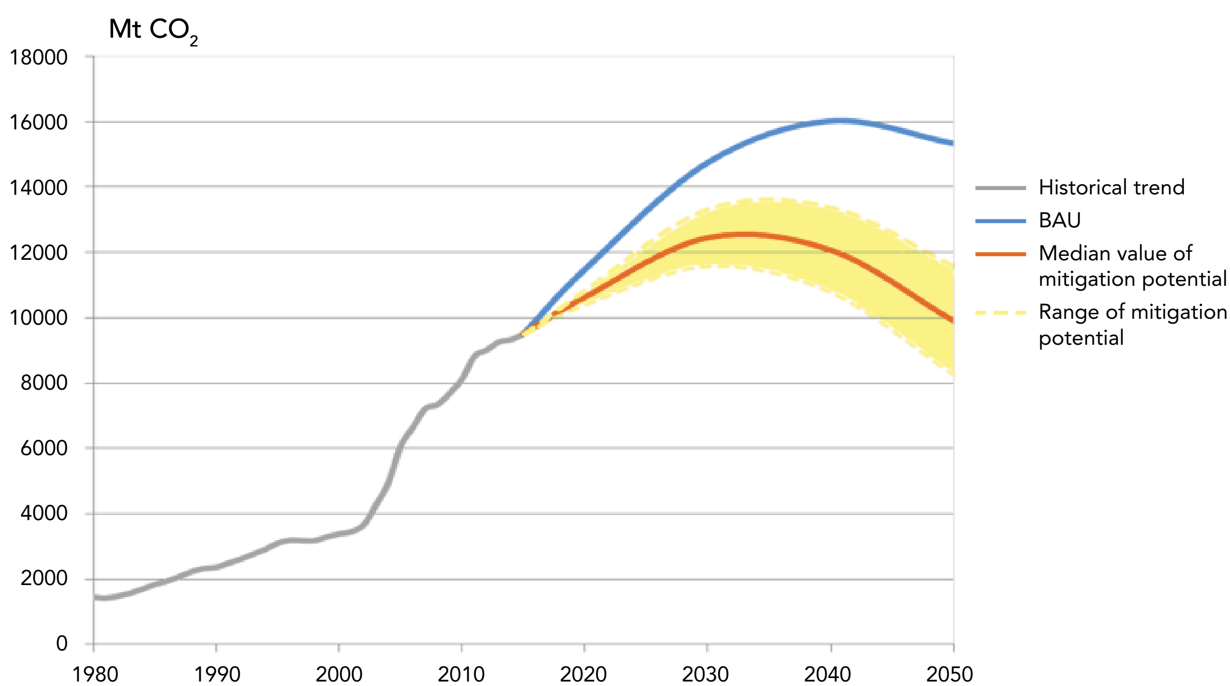
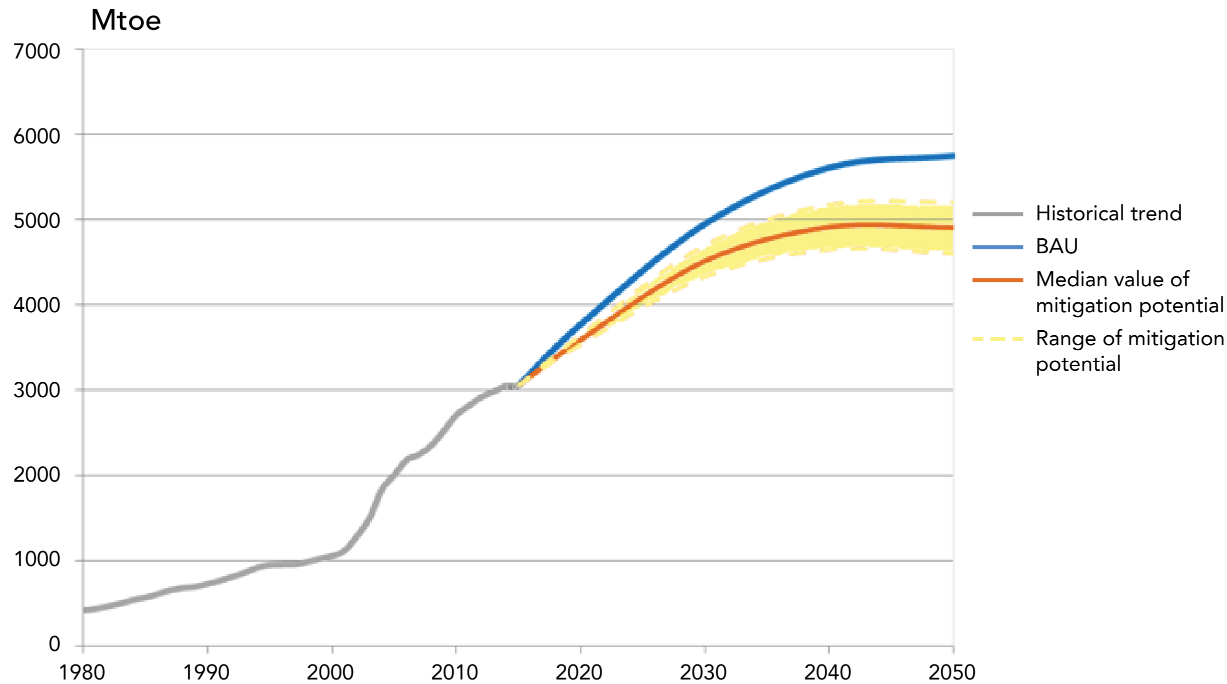


FIGURE 2.8. Primary Energy Consumption with Mitigation Efforts



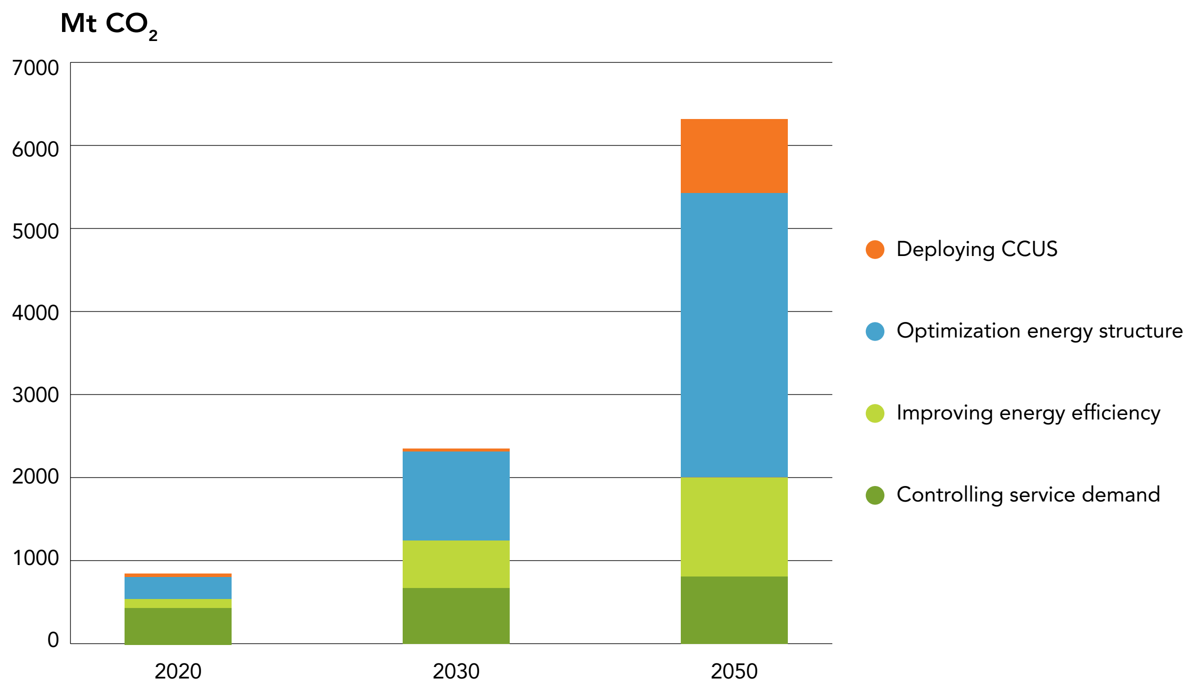
Carbon Mitigation Potential by Contribution Factors

The emissions-reduction potential of the Chinese economy can be divided into four types of factors.

- **Controlling service demand** – controlling the increasing demands for housing and transport services (e.g., per-capita floor space, vehicle ownership per 1,000 persons) at a reasonable level as urbanization proceeds. As shown in Figure 2.9, the mitigation potential achieved by controlling service demand (mainly from the building and transport sectors) could increase from 0.42 $GtCO_2$ in 2020 to 0.84 $GtCO_2$ in 2050. This would contribute to 51% and 13% of total estimated mitigation potential, respectively.
- **Energy efficiency improvements** – reducing the energy use per unit of service demand by adopting more efficient technologies and improving system efficiency through energy management systems control, e.g., energy efficiency for northern urban area heating supply, fuel economy for vehicles, etc. This might account for 15% of emissions reductions in 2020, rising to 19% in 2050, equivalent to 0.12 $GtCO_2$ in 2020 to 1.2 $GtCO_2$ in 2050.
- **Energy structure optimization** – increased deployment of low-carbon energy, i.e., natural gas, nuclear and renewable energy to diversify and optimize the energy structure. Achieving the levels of decarbonization required under the new development pathway will require a shift away from coal in primary energy use towards gas and electricity, with electricity generated increasingly from renewable and nuclear sources. The share of coal in primary energy consumption might fall from 70% in 2010 to around 50% in 2030, while the share of nonfossil fuels and natural gas will need to almost treble over the same period. The share of electricity in total final energy consumption would also be expected to grow to almost one quarter, driven by factors such as the increasing penetration of electric vehicles. The emission reductions delivered from this source could rise from 0.28 $GtCO_2$ in 2020 to 3.4 $GtCO_2$ in 2050—35% and 54% of total mitigation potential respectively.

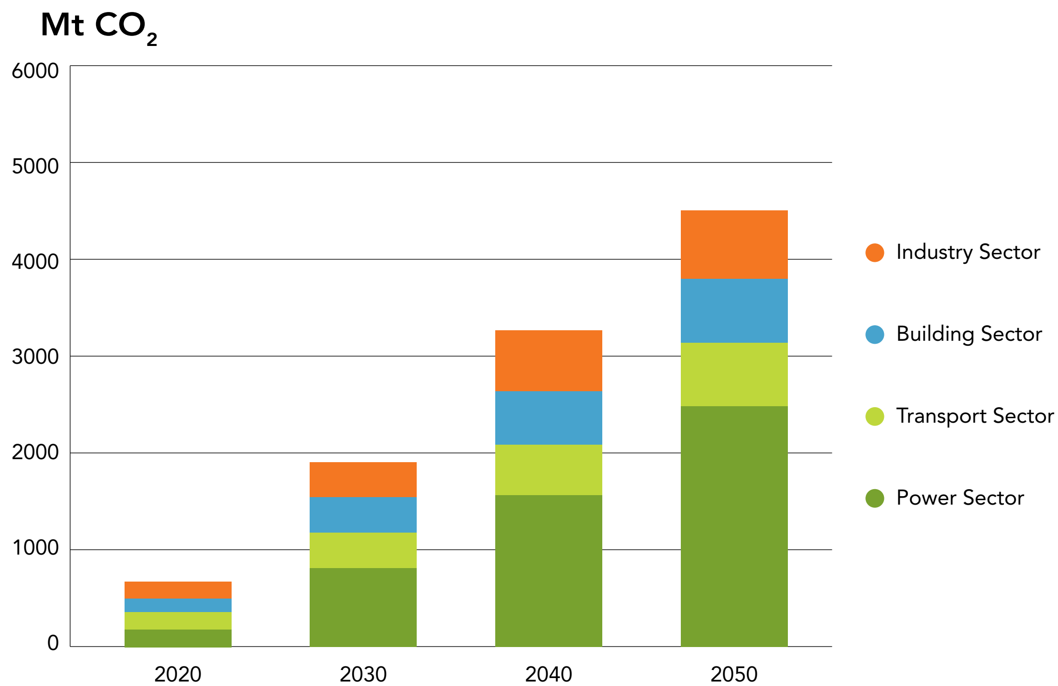
- **Deploying CCUS technologies** – capturing CO_2 and using or storing it rather than releasing it to the atmosphere. This could play a major role in the post-2030 period, with carbon-mitigation potential reaching 0.9 $GtCO_2$ in 2050, 14% of total mitigation potential. This will require accelerating technology development, promoting demonstration projects, improving the regulatory framework and providing a substantial price signal from the government.

FIGURE 2.9. CO_2 Mitigation Potential of Different Factors



Different sectors have varying mitigation potential over time. The nonfossil fuel target in the NDC would require the rapid development of renewable energy, which is mostly consumed in the power sector. This means that the power sector has the largest mitigation potential over the period, as shown in Figure 2.10, which would need to be delivered by the extension or enhancement of current policy and measures, such as preferential policies on nonfossil fuel development and improved efficiencies of thermal power, as cited in the NDC. Its mitigation potential is estimated to be 0.24 $GtCO_2$, 0.99 $GtCO_2$ and 3.0 $GtCO_2$ in 2020, 2030 and 2050, respectively, accounting for 30%, 43% and 55% of the total. The industrial emissions-reduction potential might be 0.21 $GtCO_2$ in 2020 to 0.42 $GtCO_2$ in 2030, and 0.85 $GtCO_2$ in 2050, although this implies the proportion of the total mitigation potential would fall from 26% in 2020 to 18% in 2030 and 16% in 2050. Along with greater urbanization, the low-carbon development of the building and transport sectors is expected to play an increasingly important role, much of which comes from the electrification of end-use application, particularly in the long term. The carbon-mitigation potential of the building sector is projected to be 0.15 $GtCO_2$ in 2020 and 0.8 $GtCO_2$ in 2050, with the associated contribution to total reduction potential of 18% in 2020 and 15% in 2050. The carbon-reduction potential of the transport sector is expected to be 0.22 $GtCO_2$ and 0.8 $GtCO_2$ in 2020 and 2050, implying its contribution to the total reduction might be 26% in 2020 and 15% in 2050.

FIGURE 2.10. CO_2 Emissions-Reduction Potential by Sector



Implementing the NDC: A Modelling Scenario

The NDC can support the implementation of the innovative development pathway throughout the Chinese economy and tackle all emissions drivers. This NDC scenario starts with the BAU trajectory described in section 2.2 and using the understanding of the abatement potential discussed in sections 2.3 and 2.4, it identifies how China's NDC might be met so as to potentially guide its implementation. While there will be many challenges in achieving this scenario (see Chapter 3) the discussion in the following sections illustrates how it might be achieved. It explores the following issues which are key in planning China's NDC implementation:

- The structural changes that are likely to be required in the Chinese economy to meet the targets embodied in the NDC and how this differs from business as usual;
- Overall changes in the patterns of energy consumption and the sectoral changes that can allow China to achieve its NDC;
- The policy domains in which the Chinese government might introduce further reform to achieve these changes.

Assumptions on Key Drivers in NDC Scenario

The NDC scenario used in this report is based on a number of economic and demographic assumptions that influence the overall trend in emissions. Some of the key assumptions and projections associated with this analytical scenario are provided in Table 2.2 below. Population is predicted to increase before a peak at around 1,467 million in 2030. This will then gradually fall to 1,409 million in 2050. The urbanization rate will increase from 48% in 2010 to about 68% in 2030, and then to 78% in 2050, with more than 480 million people moving into cities. The GDP growth rate will slow with the economic shift to the new normal. GDP per capita is anticipated to increase more than threefold between 2010 and 2030, and more than sixfold between 2010 and 2050. The economy will be restructured with the shift to the new normal. The share of primary industry will continue to decrease and the share of secondary industry will reach a peak (about 50%) between 2010 and 2015 and then begin to decrease. The share of tertiary industry will keep increasing until reaching around 58% by 2050. Demand for energy services in the building and transport sector will grow significantly until 2050, in line with economic growth. The demand for residential and commercial floor space in 2030 and 2050 will be around 1.5–1.6 times the 2010 level, respectively. Demand for both freight and passenger transportation will increase fivefold between 2010 and 2050.

TABLE 2.2. Key Assumptions and Projections in the NDC Analytical Scenario

	2005	2010	2015	2020	2030	2040	2050
Population (million)	1,308	1,341	1,375	1,408	1,467	1,442	1,409
Urbanization rate	43%	50%	56%	62%	68%	73%	76%
GDP per capita, US$ (2010 prices)	2,708	4,505	6,429	8,639	14,026	21,539	29,985
GDP growth rate	—	11.3%	7.9%	6.6%	5.4%	4.2%	3.2%
Residential and commercial floor space (billion m^2)	38.6	46.7	52.2	58.8	70.0	74.1	76.3
Residential floor space per capita (m^2)	25.2	29.0	31.1	33.8	37.7	39.3	40.3
Freight transportation (billion tonne-km)	9,394	14,454	21,070	27,686	42,337	61,398	75,660
Passenger transportation (billion passenger-km)	3,446	5,163	7,610	10,056	16,085	20,849	26,019

Note: the assumptions made are based on the review of various analysis, see annex B for more information. See footnote for GDP growth rate 2005[6]

Contribution by Key Drivers

China will need to decrease its energy intensity of GDP and carbon intensity of energy in order to meet its NDC whilst maintaining economic growth. This is the Kaya decomposition (as covered in Chapter 1) approach of breaking down emissions into the four drivers of population, GDP per capita, energy intensity of GDP and the carbon intensity of energy. While care needs to be taken in using this methodology in relation to forward looking projections, it provides a useful device for explaining the possible changes in the structure of the economy. The details of this analysis are shown in Figures 2.11 and 2.12 and Table 2.3. The importance of further economic development means that economic growth is expected to continue to be a significant driver of China's emissions. Economic growth projections indicate that China's GDP per capita will grow substantially. Relative to 2005, analysis suggests that China's GDP per capita will grow by multiples of 3.2, 5.2, and 11 by 2020, 2030, and 2050, respectively. Population will also be a driver of emissions, and is projected to increase by 2030 but then to remain stable to 2050. .

6 This growth rate figure is missing since the growth rate is related to a period over the preceding time period. For example, for 2010 the listed for growth rate is for the period 2005-2010. As the 200 data is not listed this growth rate figure has been excluded.

FIGURE 2.11. Key Drivers of China's Emissions in NDC Scenario Modelling

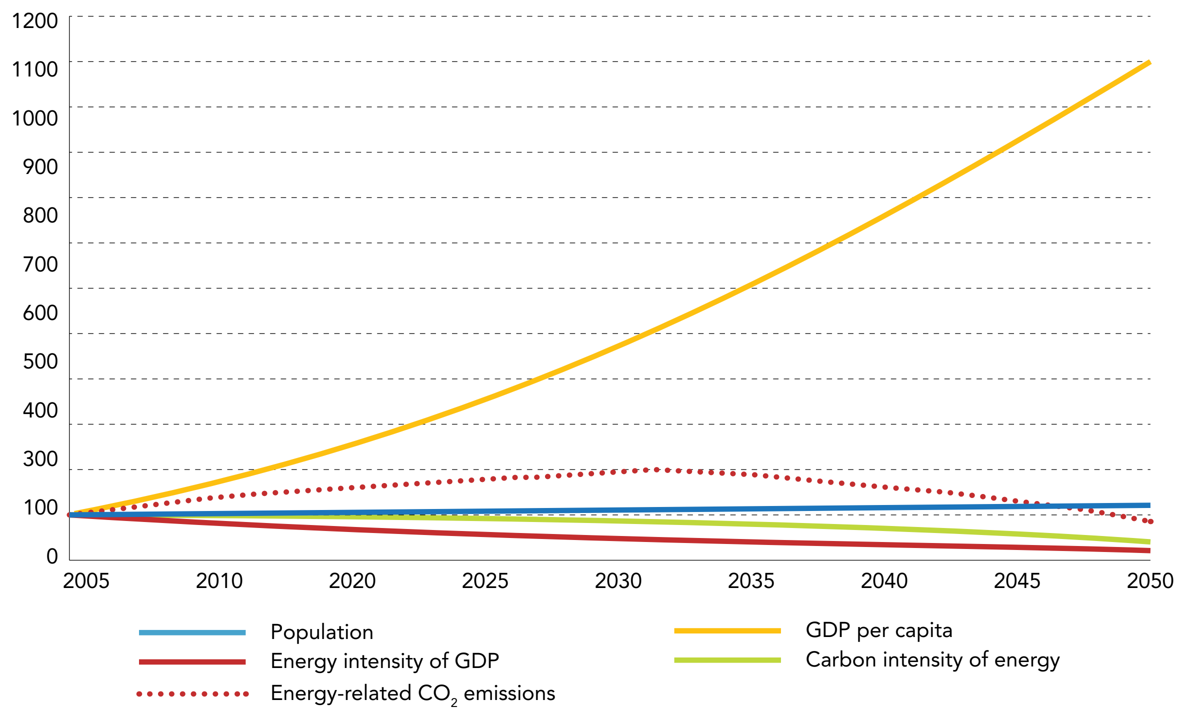
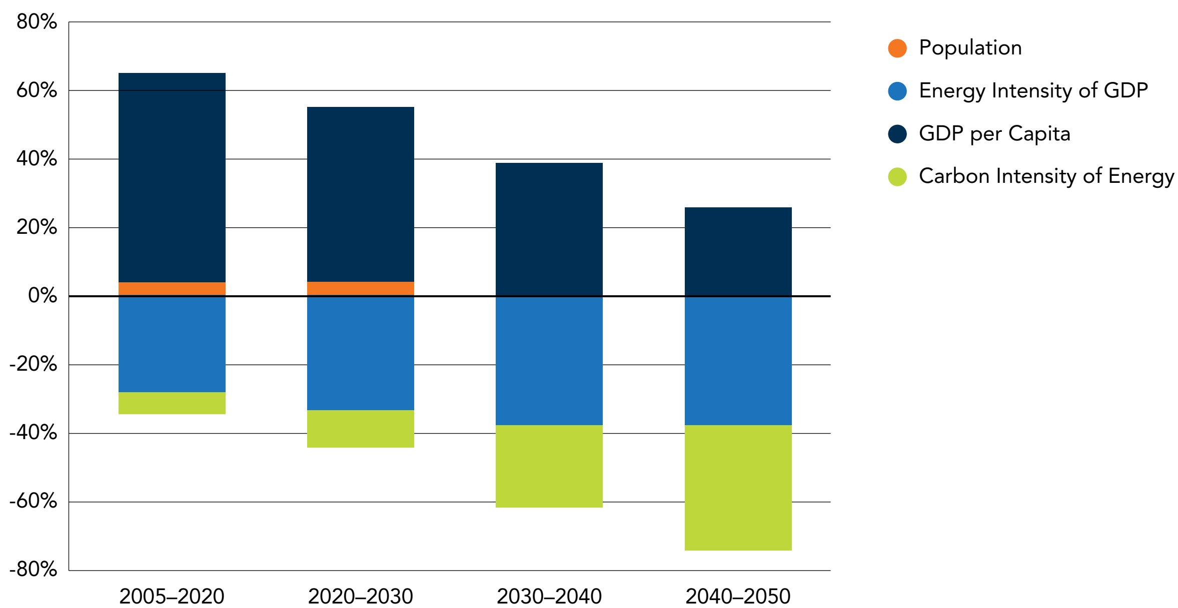


FIGURE 2.12. A Kaya Decomposition of China's Emissions



Source: 2005 and 2010 data are from *China Statistical Yearbook*, *China Energy Statistical Yearbook* and China's official review of target completion. Data after 2015 are from an NDC scenario from PECE model developed by NCSC and Renmin University of China.

Accommodating this economic and population growth while meeting the NDC targets means that significant improvements in the energy intensity per unit of GDP will be required. Figure 2.12 demonstrates the projected decreases in the rates of energy and carbon intensity in the NDC scenario. It suggests reductions in the energy intensity of GDP will be central in limiting emissions growth by 2030:

energy intensity is expected to fall to around 40% of 2005 levels by 2030. Post-2030, energy intensity will decrease further, potentially reaching 20% of 2005 levels by 2050. The analysis shows that this change will be fundamentally supported by structural economic shifts as shown in Table 2.3 below.

TABLE 2.3. Part of Shifting the Chinese Economy to a New Normal Involves the Development of Tertiary Industry

	2005	2010	2015	2020	2030	2040	2050
Primary Industry	11.7%	8.5%	7.2%	6.3%	5.6%	5.1%	4.7%
Secondary Industry	46.9%	48.8%	48.8%	45.8%	42.3%	39.1%	37.3%
Tertiary Industry	41.4%	42.7%	44.0%	47.9%	52.1%	55.8%	58.0%

Note: Industry proportions calculated based on 2010 prices.

Source: 2005 and 2010 data are from *China Statistical Yearbook*. Data after 2015 are from an NDC scenario from PECE model developed by NCSC and Renmin University of China.

The analysis suggests reductions in the carbon intensity of energy consumption will be relatively less important in limiting 2030 emissions (with 2030 levels potentially at 80% of 2005 levels) but much more important beyond 2030. Decarbonization of the energy supply becomes a more important driver beyond 2030, especially in the period 2040–2050. These patterns reflect the expected growth in the availability of low-carbon technologies in the medium to long term.

Contribution by Key Sectors

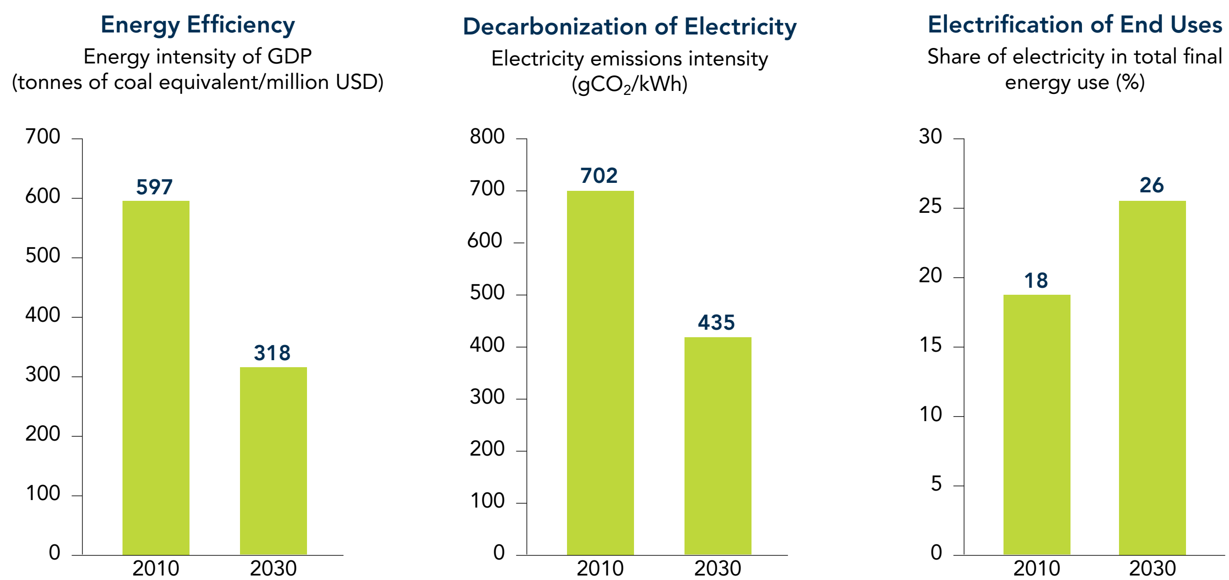
The realized emissions-reduction potential can also be analysed by sector. The discussion below first illustrates how overall patterns of energy supply are projected to change under the NDC scenario before discussing specific patterns in key energy end-use sectors: buildings, transport and industry.

Energy Supply Sector

Achieving the levels of decarbonization required under the new development pathway will require a shift away from coal in primary energy use towards gas and electricity. The share of coal in primary energy consumption is expected to fall from 71% in 2010 to 50% in 2030, while the shares of nonfossil fuels and natural gas are predicted to increase from 7.9% and 3.8% in 2010 to 22% and 9.2% in 2030, respectively. The share of electricity in total final energy consumption is expected to grow to almost one-quarter, driven by factors such as the increasing penetration of electric vehicles (Figure 2.13).

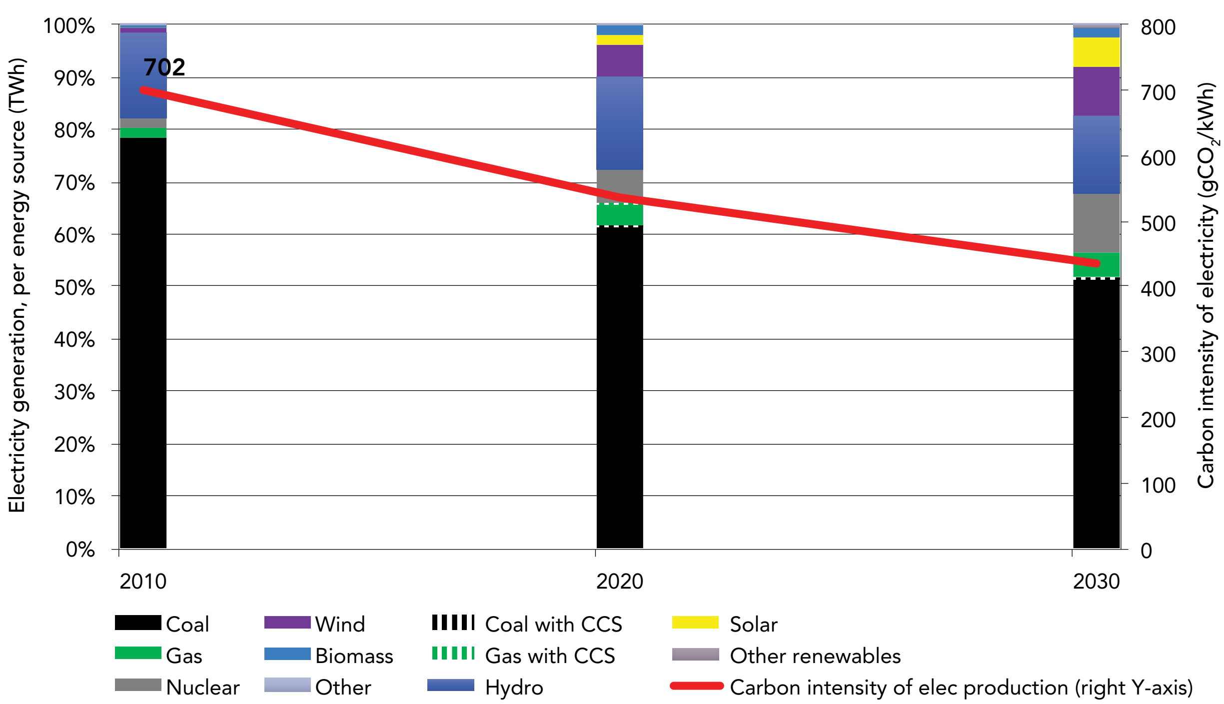
Greater electrification makes decarbonization of the power sector crucial. In this scenario, nonfossil fuels will gradually dominate the power sector, facilitated by continuous support policies and measures, including increasing research funds into cost reduction, higher priorities for newly built nonfossil fuel power plants, and feed-in tariffs for renewable power plants. The share of all renewables in total power generation is expected to rise to 30% in 2030, while nuclear energy might take another 12%. Combined with the application of carbon capture and storage (CCS) in thermal power generation, CO_2 emissions per unit of electricity generation in 2030 might be reduced by more than 40% from the 2010 level (Figure 2.14). This can make a significant contribution to reducing the carbon intensity per unit of energy use in China. By 2030, China's installed capacity of nonfossil power is expected to increase by over 900 gigawatts from 2014 levels, an increase roughly equivalent to the country's total installed thermal power capacity in 2014. As shown in Table 2.4, average annual installation of nonfossil capacity could increase from around 42 gigawatts per year in the period from 2005–20 to 66 gigawatts during 2020–30, and to potentially 87 gigawatts in the 2030–50 period.

FIGURE 2.13. Changes in Key Indicators Under the NDC Scenario



Source: 2010 data are from *China Statistical Yearbook*. 2030 data are from an NDC scenario from the PECE model developed by NCSC and Renmin University of China.

FIGURE 2.14. Power Generation by Source in China in the NDC Scenario



Source: NDC scenario from the PECE model developed by NCSC and Renmin University of China.

TABLE 2.4. The Deployment of Nonfossil Fuel Energy 2005–2050

	2005-20	2020-30	2030-50
Annual average new installed capacity of non-fossil power generation (GW) (breakdown below)	41.8	65.6	87.1
Wind power (GW)	14.2	23.8	35.6
Solar power (GW)	7.0	25.0	36.4
Nuclear power (GW)	3.4	9.2	10.6

Source: From an NDC scenario from PECE model developed by NCSC and Renmin University of China

End-Use Sectors

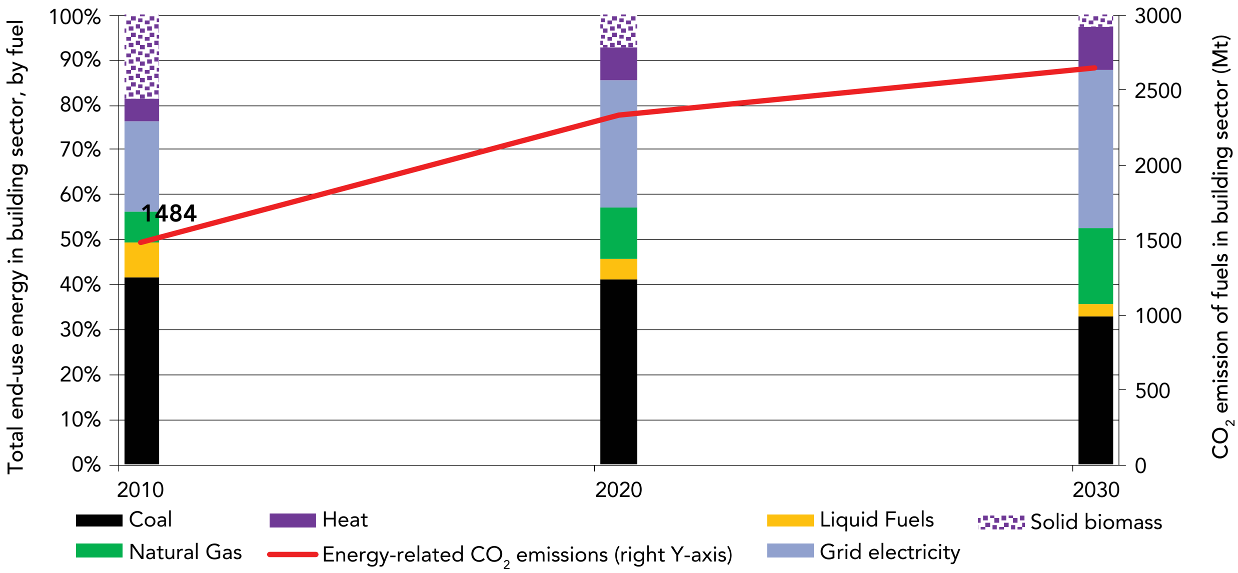
Given China's unique development status in relation to industrialization and urbanization, there are expected to be different trends in different end-use sectors in relation to both energy consumption and emissions in the NDC scenario. Industry is expected to remain the biggest end-use energy consumer before 2030; its final energy consumption might increase 52% on its 2010 level, and its emissions are anticipated to peak at around 7,100 Mt between 2020 and 2025. Transportation and building, the two sectors closely related to urbanization, are expected to see enormous increases in final energy demand, with their final energy consumption in 2030 potentially increasing by 133% and 102%, respectively, on their 2010 levels, and their emissions peaking at around 2,650 and 1,850 Mt, respectively, between 2030 and 2035.

While China's development needs in advancing living standards and eliminating poverty serve as drivers for its economic growth, it also generates great production and service demands that increase its energy consumption and CO_2 emissions. Hence, keeping the increase of service demands at a manageable level and converting industrial production patterns onto a more sustainable path are prerequisites for China's low-carbon development, and policies and measurements guiding both producers and consumers are much needed.

In the **building sector**, administrative measures such as improved urban planning and restrictions on the demolition of old buildings, as well as economic measures such as taxes on residential buildings, are projected to restrict the increase in public building area per capita and residential building area per capita to 11.5 m^2 and 37 m^2, respectively, by around 2030. This is similar to major EU countries' current levels[7]. In addition, by improving the insulation properties of buildings and heating pipelines, as well as using waste heat and efficient heating technologies, the heating energy consumption per unit of area in the northern heating area can decrease by about 35% by 2030 compared with the 2010 level. Better implementation of clean and low-carbon energies, including heat, natural gas, electricity and distributed renewables is also projected to allow the proportion of coal consumption to decrease from 42% in 2010 to 33% in 2030, while that of electricity and gas is projected to rise from 20% and 7% in 2010 to 35% and 17% in 2030.

7 BPIE, Data hub for the energy performance of buildings, http://www.buildingsdata.eu/

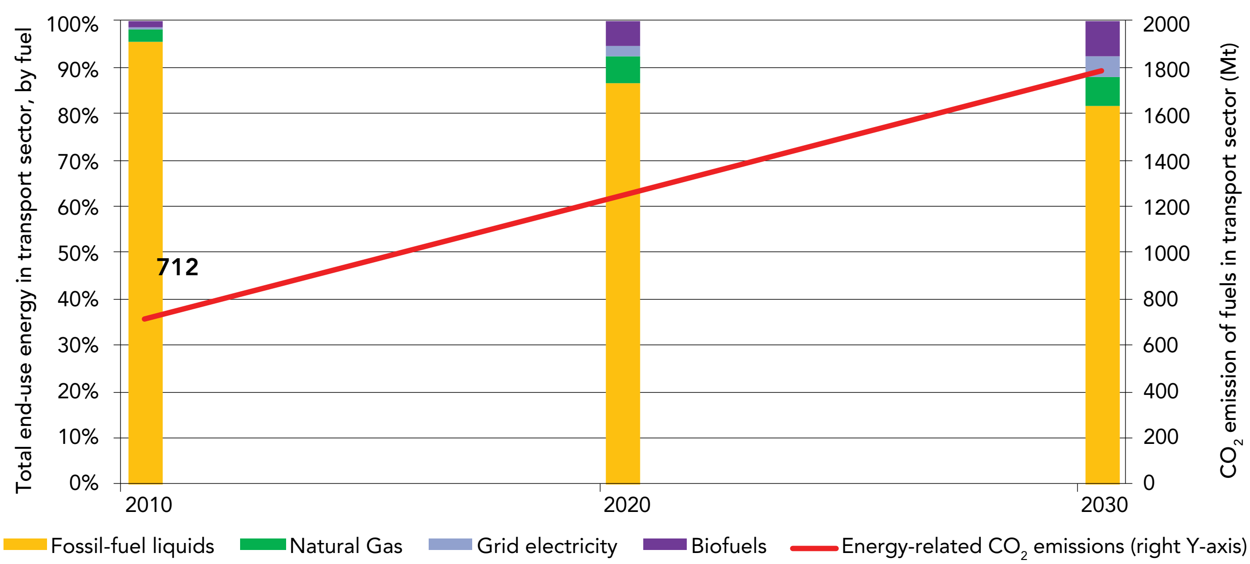
FIGURE 2.15. Emissions Trends and Energy Mix in the Building Sector, 2010–30



Source: NDC scenario from the PECE model developed by NCSC and Renmin University of China.

In the **transport sector**, greater public transport capacity (such as mass MRT, BRT), as well as intelligent transport management, are anticipated to restrict freight and passenger turnover growth by 2050 to 2.8 times and 3.6 times their 2010 levels, while car ownership per thousand persons in 2030 might increase to 200—one-quarter of U.S. levels in 2010[8]. The implementation of stricter vehicle fuel economy standards can contribute to an increase in the fuel economy of light-duty vehicles of 20% between 2010 and 2030. Many types of low-carbon vehicles will also gradually take dominant roles, such as 100% electrically powered vehicles (EPV), plug-in hybrid electric vehicles (PHEV), and fuel-cell vehicles (FCV). EPV is projected to account for more than 25% of total light-duty vehicles in 2030, and the use of biofuel will be an important option in reducing gasoline and diesel use.

FIGURE 2.16. Emissions Trends and Energy Mix in the Transport Sector, 2010–30

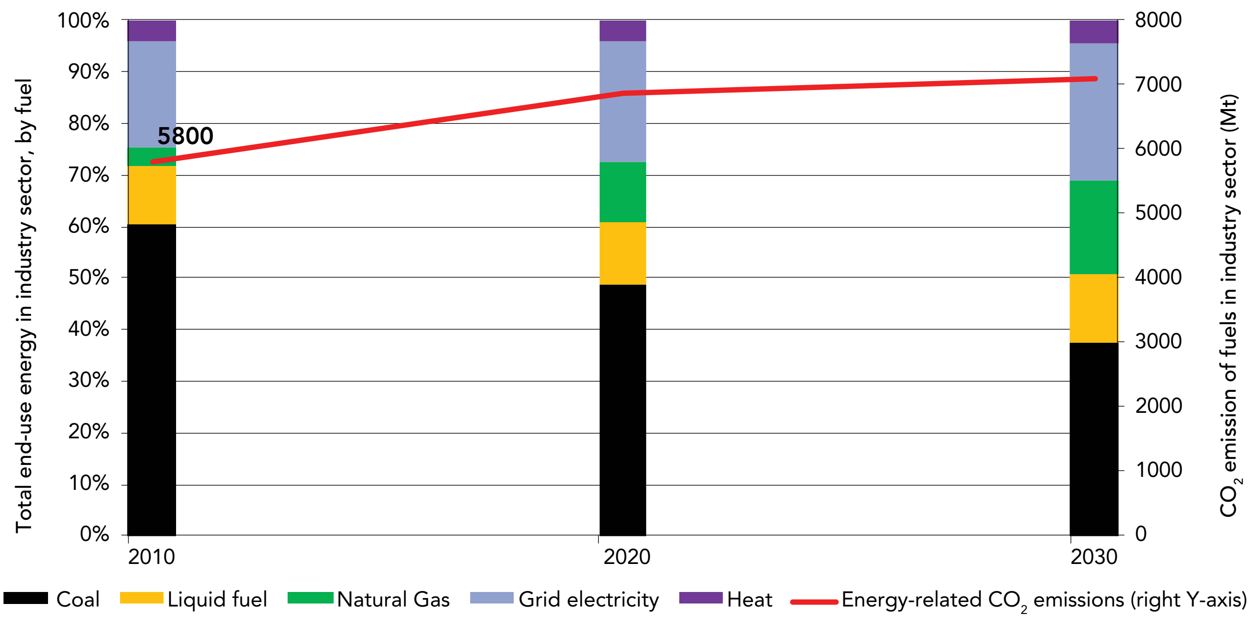


Source: NDC scenario from the PECE model developed by NCSC and Renmin University of China.

8 Wardsauto, http://wardsauto.com/special-reports/2011

In the **industry sector**, promoting the development of tertiary industry, controlling overcapacity of major energy-intensive industrial outputs, and eliminating backward production capacity could result in the share of secondary industry in GDP decreasing gradually from 46.2% in 2010 to 38.5% in 2030—close to that of Germany in the mid-1990s and the world average level in the early 1990s. This can be supported by the adoption of energy-saving technologies, such as efficient waste-heat recycling technologies and efficient boilers and motors. Collectively these measures will allow energy consumption to be decoupled from the growth of the industry sector, with final energy consumption potentially growing by 50%, despite industry value-added projected to increase by 178% between 2010 and 2030. The energy consumption per value-added of the industry sector is expected to fall by 45% over the period in this scenario. In addition, promoting the transformation of coal-fired boilers to gas-fired boilers, and enhancing the use of electricity might allow the share of gas and electricity to increase to, potentially, 18% and 31% in 2030, respectively, from less than 4% and 21% in 2010, while coal use is expected to decrease from 61% in 2010 to 37% in 2030.

FIGURE 2.17. Emissions Trends and Energy Mix in the Industry Sector, 2010–30



Source: NDC scenario from the PECE model developed by NCSC and Renmin University of China.

Policies and Measures to Meet the Targets

A wide range of policies and measures will be needed to help meet the NDC targets and drive China's transition towards the innovative development pathway. Some specific measures and policies were identified in the section above but significant further research is required to identify the precise policy mix required. Table 2.5 identifies the main domains in which policies to support the implementation of the NDC will need to be developed.

TABLE 2.5. An Overview of Domains Where Detailed Policy Design and Implementation is Required

Overarching National Strategies	***Implementing proactive national strategies on climate change,*** including enacting climate change law, integrating climate change into mainstream social economic strategies and developing long-term strategies and roadmaps for low-carbon development.
	Improving regional strategies on climate change, including decomposing national targets to the local level, development of regional low carbon strategies, promoting advanced regions to peak their emissions early, control of emissions and carbon intensity at the urban development zone level, etc.
	Innovating a low-carbon development growth pattern, such as through low-carbon pilots in provinces, cities and industrial zones.
	Promoting international cooperation on climate change, such as by actively engaging in international cooperation and establishing a Fund for South-South Cooperation on Climate Change.
Energy System Changes	***Building a low-carbon energy system***, including the shift away from coal and the development of renewables and nuclear power through policies like phasing out coal in specific regions, emission and energy standards for electricity supply, subsidies and quotas for electricity, reform of the electricity and energy pricing mechanism to take account of carbon scarcity, supply-demand conditions and other environmental costs, etc.
Support for Science and Technology	***Building an energy-efficient and low-carbon industrial system***, including the promotion of low-carbon industries, control of industrial emissions by, for example, phasing out obsolete capacity, setting key industry investment entry barriers, improving energy efficiency and promoting decarbonization in energy intensive industries, as well as the promotion of recycling systems, etc.
	Enhancing support for science and technology, including strengthening R&D on low-carbon technologies
	Improving statistical and accounting systems for greenhouse gas (GHG) emissions, including regular GHG inventories and reporting requirements at national and provincial levels, carbon emission certification, etc.
Sectoral Plans	***Controlling emissions from the building and transportation sectors***, for example through low-carbon urbanization planning, optimized green transportation systems, stricter building codes, improving energy standards for electric devices, promoting distributed renewables, etc.
	Increasing carbon sinks in forests, wetlands and grasslands
	Enhancing overall climate resilience, for example, through infrastructure development and improved assessment and risk management of climate change
Incentives and Behavior	***Increasing financial and policy support***, which might include the use of funds, innovative carbon financing mechanisms, preferential taxation policies, green government procurement systems green credit mechanisms, etc.
	Promoting carbon emissions trading markets, building on emissions-trading pilots
	Promoting a low-carbon way of life, by exploring ways in which to support low-carbon choices in daily life
	Increasing broad participation of stakeholders, in order to increase public- and private-sector awareness of low-carbon development

There is likely to be an increasing emphasis on the role of market-based measures and economic incentives. The policy review provided in Annex A shows that command-and-control policies have played an extremely important role in helping China mitigate its emissions thus far. In the future, economic instruments such as emissions trading, implemented in supportive market structures, will play an increasingly important role as China implements its NDC targets. This may require reform to the institutional set-up within the country in order that these market structures and price signals can be effective and that they are not undermined by contradictory signals or regulation as is sometimes the case at present. An increasing role for economic incentives and market-based institutions can play a crucial role in making the country much more flexible, entrepreneurial, resource-efficient, innovative, and clean.

Throughout, China's policies and measures will have the following three characteristics:

- A link with other development agendas and priorities, such as local air-quality improvement;
- In the context of international cooperation, integrating the concept of low-carbon and environmental standards into strategies like the 'one belt and road' initiative;[9]
- A long-term vision to avoid the risk of lock-in.

Further development of the policy suite for NDC, in a manner that is consistent with China's overarching economic development strategy, will require further modelling and qualitative analysis. This future analysis can help understand in greater detail what policies might be introduced in order to help meet the NDC and what the implication of these policies might be, given the existing suite of policies and institutions within the country. There are a number of tools that might be used to support this analysis:

- **Computable General Equilibrium models** could help capture the impact of NDC implementation on structural changes in the economy and macroeconomic aggregates. These will help capture the direct and indirect feedbacks between economic actors and provide more detailed understanding of the potential costs of NDC implementation;
- **Agent based models** would help simulate the impact of policy and financial drivers on investors and consumers behavior, and hence design the reform packages to ensure effective implementation of NDC objectives.

Progress Towards the 2° Goal: Implications of the NDC Scenario and an Enhanced Ambition Scenario

Progress towards and attainment of the existing 2030 NDC targets will lay a strong foundation for China to further accelerate emissions reductions in the period beyond 2030. Successful implementation of the NDC will enable China to improve its approach to development, consolidate public support, further refine its policies and institutions, build technological and innovative reserves, and develop comprehensive and specialized capabilities to respond to climate change. These benefits are built into the long-term emissions projections in this analysis. These suggest that emissions could fall by around 50–60% on their 2030 levels by 2050, returning emissions to roughly the same level as in 2005, despite a more than 1,000% growth in GDP per capita.

Enhanced post-2030 actions will have implications for the global carbon budget. The recent IPCC Fifth Assessment Report (AR5) includes a series of forecast scenarios that have a likelihood (of at least 50%) of limiting global temperature increases to within 2°C. These scenarios identify emissions-reduction requirements for China that, if combined by action by the rest of the world, are largely consistent with the targets set by China's NDC. Figure 2.18 shows the pathways for China's emissions in which NDC commitments are included to 2030, with strong reductions thereafter as identified in this analysis (depicted as dotted lines). This figure shows that the NDC scenario is consistent with the range of emissions for China in the IPCC AR5 scenarios and therefore the attainment of the 2°C goal.

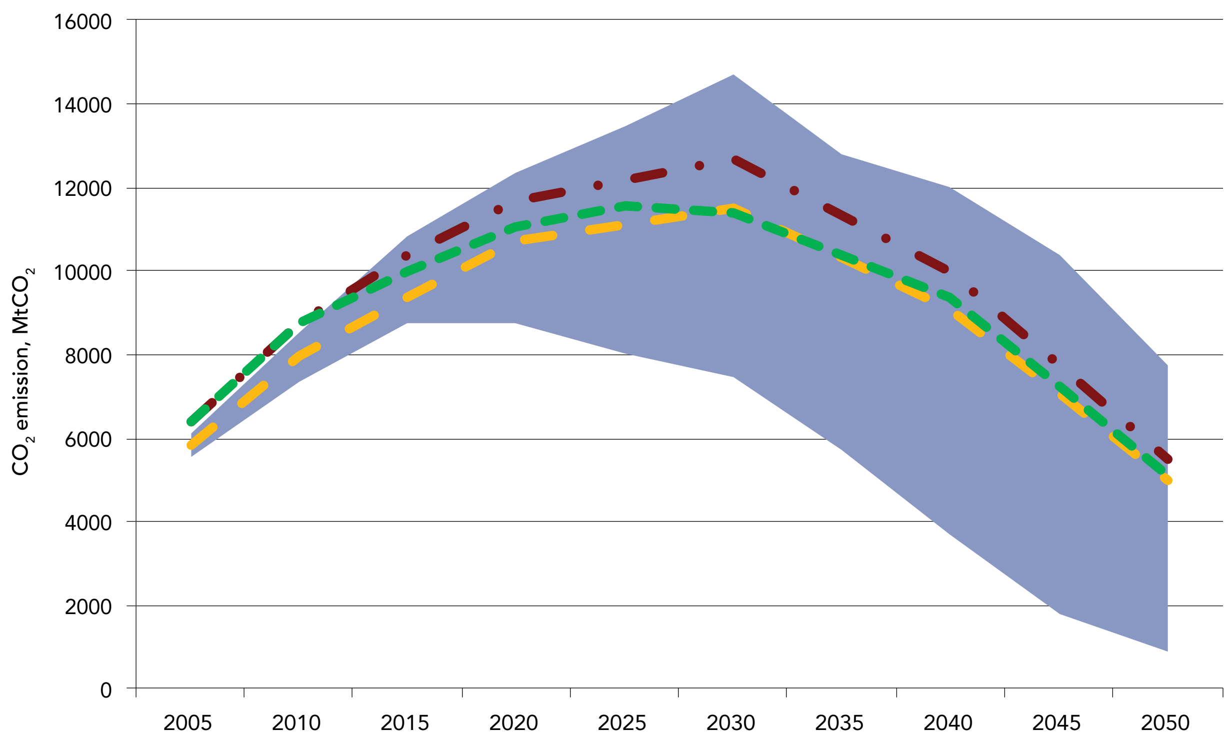
China appears on track to achieve its NDC goals and has significant potential to further enhance its action. Recent trends in China's economy, energy consumption and CO_2 emissions, have led some

9 This is a Chinese economic and political strategy espoused by Xi Jinping. It involves linking the two ends of Eurasia as well as Oceania and Africa through major land-based ('Silk Road Economic Belt') and maritime ('Maritime Silk Road') trade routes in order to enhance cooperation and connectivity.

to argue that China can and will peak its emissions much earlier than 2030 and may even overachieve on its NDC target. For example, an ESRC and GRI joint report states that China's annual emissions of greenhouse gases may peak even before 2025, as its consumption of coal, a major source of carbon dioxide emissions, was 2.9% lower in 2014 compared with 2013 (Boyd et al., 2015). China has a history of overachieving on its climate targets and it appears it will likely do the same with the 2020 targets it put forward as part of its Copenhagen pledge in 2009. In China's recently published 13th FYP Plan, China has announced a further carbon intensity reduction target of 18% for the 13th FYP, which means, in total, China's carbon intensity will be reduced by around 50% compared to the level of 2005 compared with the 40–45% target set out in the Copenhagen pledge.

According to our scenario analysis of an enhanced ambition scenario (Figure 2.18), China has the potential to achieve its peak during 2025–2030, and the carbon intensity target and nonfossil fuel target can be increased to 65–75% and 23%, respectively. However, the full achievement of this enhanced action depends on overcoming a number of challenges and uncertainties. These include effective implementation of China's economic and political reform, the further development of low-cost, low-carbon technology, the change of production and consumption patterns, etc. This is explored in more detail in Chapter 3.

FIGURE 2.18. China's Projected Emissions Under NDC Commitments are Consistent with IPCC '2 Degree Future' Scenarios



Note: The purple area represents IPCC AR5 emissions scenarios for China with more than 50% probability of achieving the 2° goal given China's current status. Red and yellow lines indicate China's emissions trends after implementing NDC targets (with and without energy data adjustment following latest economic census). The green lines indicate an enhanced ambition scenario. To ensure comparability with global data, the CO_2 emissions here include energy-related CO_2 emissions plus CO_2 emissions from cement production.

Source: IPCC AR5, PECE model developed by NCSC and Renmin University of China.

Challenges for and Co-Benefits of the Innovative Development Pathway

SUMMARY

There are numerous opportunities and co-benefits associated with climate action. These include domestic co-benefits such as reducing air pollution and increasing 'green' employment. International benefits include the development of a comparative advantage in the international trade of low-carbon technologies and providing an example for other developing countries to follow.

However, various uncertainties and challenges could impede the innovative development pathway and the shift to the new normal. These include uncertainty as to when new technologies will be available, financing challenges and difficulties in accessing natural resources.

With adequate planning many of these challenges can be effectively managed.

The Co-Benefits of the Innovative Development Pathway

The successful transition to the innovative development pathway offers China multiple co-benefits and opportunities. The benefits of low-carbon growth cover a wide range of issues, ranging from domestic health, security and economic transformation through to international trade and politics.

Health Co-Benefits

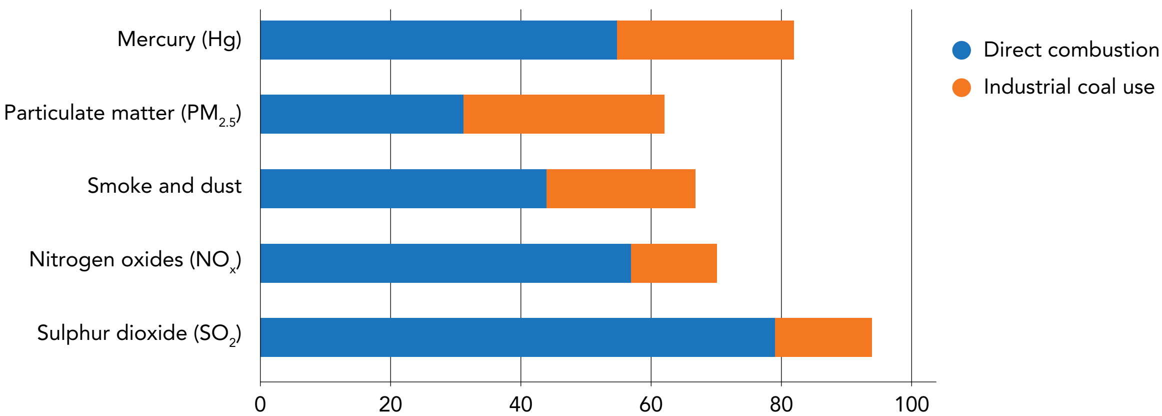
A key co-benefit of a low-carbon development pathway would be a reduction in air pollution, with significant benefits for human health and ecosystems. The main sources of air pollution are coal-fired power plants and industrial processes. As Figure 3.1 shows, around two-thirds of emissions of major pollutants (including sulphur dioxide, nitrogen oxides, particulate matter, smoke and dust, and mercury) are a direct result of coal combustion and industries closely related to coal. Indeed, coal combustion is the most important source of particulate matter (PM2.5) pollution in China. At the national level, coal use contributes around 50–60% to annual concentrations of PM2.5 (see Figure 3.2).

Public health benefits from reduced air pollution alone may be sufficient to turn net mitigation costs into net mitigation benefits. The adoption of low-carbon technology that reduces coal use will impact public health both directly and indirectly:

- Direct health effects include improvements in health of workers who are engaged in coal-related occupations, including through a reduction in pneumoconiosis, occupational poisoning and accidents. The study 'The Influence of Coal Consumption Reduction on Public Health and the Cost Avoided' (the group of China's coal consumption control scheme and policy research, 2015) concluded that there is a strong, positive correlation between the long-term exposure of coal miners to pollutants and the incidence of pneumoconiosis;

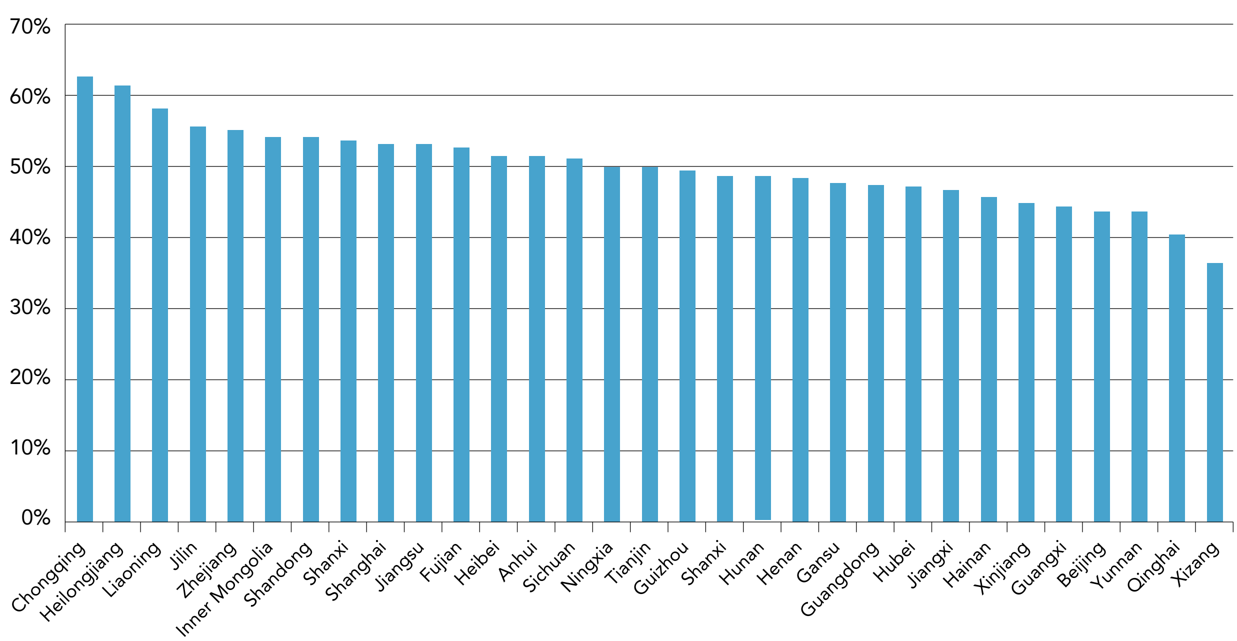
- Indirect health effects relate to health improvements of the general public due to reduced pollutants emitted as a result of combustion and processing of coal. The group of China's coal consumption control scheme and policy research also analyzed the health and economic damage caused by coal in different scenarios (Tables 1.1 and 3.2). Comparing the baseline scenario with the coal-control scenario suggests that the death rate of four diseases can be reduced by 4.9, 8.9, 8, 5.1 (per 10,000 people), and that the economic damage done by these diseases can be reduced by 384.6, 707.8, 634.1, 405.1 (billion yuan).

FIGURE 3.1. Coal Combustion for Power Generation and Industry Coal Use Are the Main Drivers of Air Pollution in China



Source: Natural Resources Defense Council, 2016.

FIGURE 3.2. The Contribution Rate of Coal Use to the Concentration of PM2.5 in Each Province



Source: The group of China's coal consumption control scheme and policy research, 2014

TABLE 3.1. Health Damage Caused by Coal Under Different Scenarios (10,000 people)

Time	Baseline Scenario	Coal-Control Scenario	Number of Avoided Deaths
2020	62.9	58	4.9
2030	46	37.1	8.9
2040	24.2	16.2	8
2050	13.1	8	5.1

Source: The group of China's coal consumption control scheme and policy research, 2015

TABLE 3.2. Economic Damage Caused by Coal Under Different Scenarios (billion yuan)

Time	Baseline Scenario	Coal-Control Scenario	Number of Avoided Deaths
2020	4,996.6	4,612	384.6
2030	3,659.4	2,951.6	707.8
2040	1,923.9	1,289.8	634.1
2050	1,044.6	639.5	405.1

Source: The group of China's coal consumption control scheme and policy research, 2015

There is a need for further work that links implementation of China's NDC and the health co-benefits it might bring. This could build explicitly from the NDC scenario developed in this report.

Economic Co-benefits

Some studies suggest that low-carbon policies will have a net positive impact on employment. New low-carbon jobs are expected to emerge in numerous industries such as renewable energy, transport and construction. For example, according to a recent report from IRENA[10], the renewable energy industry in China employed around 3.5 million people, exceeding the 2.6 million employed in the country's oil and gas sector. In the field of solar PV, the number of jobs increased by 1% to 1.65 million in 2015 while in the wind sector employment grew by 1% to reach 507,000 jobs. Similarly, the National Center for Climate Change Strategy and International Cooperation (NCSC) analysis[11] shows that new kinds of jobs are being created in sectors such as carbon finance, stocktaking, carbon performance contracting, carbon assets trust business, energy, internet and so on. While low-carbon employment gains will be partially offset by losses in employment in carbon-intensive power generation and related industries, recent studies (Cai, et al., 2014) suggest that the net impact of low-carbon policies on employment will be positive.

Other analyses[12] suggest that the greatest employment opportunities will arise if China can create new global comparative advantages in low-carbon technology and avoid carbon lock-in. The innovative development pathway can give rise to new capabilities that have the potential to create comparative advantages in international trade. If China can bolster its capabilities, some of the most attractive opportunities are likely to be in energy conservation, environmental protection, new energy, and energy-efficient vehicles. Policies to support these emerging industries have the potential to create new path dependencies that redirect R&D efforts towards these new technologies, creating a virtuous circle between deployment and R&D. This can help the country avoid the lock-in of carbon-intensive infrastructure.

10 International Renewable Energy Agency(IRENA), Renewable Energy and Jobs Annual Review 2016, http://www.se4all.org/sites/default/files/IRENA_RE_Jobs_Annual_Review_2016.pdf
11 http://epaper.21jingji.com/html/2015-07/06/content_5271.htm
12 World Bank China 2030 report

Implementing NDC targets requires increasing energy efficiency and achieving an energy transformation. In doing so, China will mainly depend on strategic emerging industries and high-end manufacturing and modern services. These cam bring a new momentum for future growth and offer the potential to reshape the competitive landscape. Studies have shown that to realize China's NDC targets, including the peaking goal in 2030, the average annual incremental low-carbon investment demand per year from 2010 to 2030 will be around EUR150–200 billion (McKinsey and Company, 2009). After the peaking year of 2030, in order to achieve a sustained decline, the average annual incremental investment will reach US$500 billion. Similarly, based on the annual data from Bloomberg New Energy Finance (BNEF), the National Center for Climate Change Strategy and International Cooperation(NCSC) analysis[13] incremental cumulative low-carbon investment would be around 4,100 billion RMB between 2005 to 2030. Investment in low-carbon technology research and development, demonstration and application will be important factors to drive China's economic structural adjustment, and has the potential to be the new engine of economic growth and employment.

The attainment of the NDC targets and China's urbanization process can be complementary. During the process of urbanization, there will be a significant need for new infrastructure and public services. This brings not only great challenges for energy consumption and GHG emissions reduction, but also opportunities for the economic and social transformation of urban environments to a low-carbon model.

Low-carbon technologies are important elements of the 'Made in China 2025' and 'Internet +' strategies, and occupy a central position in the overall national innovation strategy. In the process of implementing its NDC targets, achieving collaborative innovation in low-carbon technologies and a new generation of information and materials, technology will be an important way for China to promote new industrialization, urbanization, IT, agricultural modernization and green technology.

Security Co-benefits

Climate change impacts pose significant threats to Chinese national and energy security. These are threats that can in part be mitigated through strong domestic climate action. Climate change is likely to lead to China experiencing temperature increases greater than the global average level, as well as frequent droughts, heavy rains, flood events, and stronger landing typhoons. In sum, China is more vulnerable to climate impacts than many countries. The 'National Response to Climate Change Planning (2014–2020)' notes that:

> *'Climate change would affect China's economy and social development, and it is quite important to maintain China's economic security, energy security, ecological security, food security and people's life and property security.'*

Similarly, the Director of the National Meteorological Administration, Mr. Zheng Guoguang, has stated that:

> *'Global warming has affected the natural ecological system and the economic and social development in our country, and will also threaten our country's food security, water safety, ecological safety, and environment security, energy security, major*

13 http://epaper.21jingji.com/html/2015-07/06/content_5271.htm

> *engineering security and economic security, traditional and non-traditional security, putting forward severe challenges to national security.'*

Dodo (2014) has observed that climate change acts as a threat multiplier, amplifying environmental, energy and human security challenges, border disputes, immigration challenges, energy supply constraints, shortages of water/land/fish and other resources, social pressures, and humanitarian crises.

Formulating and implementing its NDC can play an important role in maintaining China's economic, energy, ecological and food security. Using energy security as an example, China's foreign dependency ratio for oil in 2014 was 59.3%; for gas it was 30.6%; and even for coal it had reached 6.9%. The low-carbon development strategy and target will drive an improvement in energy efficiency and the use of nationally secure renewable resources. Decarbonization can both create an independent energy supply and mitigate the impacts of climate change making it central to China's energy and national security.

International Co-benefits

China's transition to the new normal could allow for new relationships and trade with developed countries. Research and industrial collaboration between China and developed countries could significantly reduce the cost of low-carbon technologies and expand the scope of the global market of low-carbon technologies and products. Such collaboration could create benefits for both developed and developing countries. For example, a PEW Charitable Trusts report observed that China and the US have formed a strong relationship in solar energy provision: China is the main solar panel supplier to the US, while US firms provide other high-value components, such as polysilicon, chemical products and manufacturing equipment to Chinese manufacturers. Similarly, in the field of wind energy, China manufactures the turbine steel frame, while US companies provide glass fibre and electronic control devices. Thus, a mutually beneficially economic tie has formed between China and the US, the world's two largest emitters, due to collaborative renewable energy production. Such opportunities for collaboration also exist with developing countries.

China's experiences might serve as an example for other developing countries. In its transition to the innovative development pathway, China has the opportunity to demonstrate a sustainable framework for development to these countries, supported by active South-South cooperation. China has carried out energy saving and renewable energy technology and product promotion projects in 23 developing countries. In addition, it has held more than 40 workshops on dealing with climate change and low-carbon development in developing countries. By sharing China's experiences, other developing countries might avoid reliance on traditional high-carbon growth models and pursue more efficient and innovative paths that result in less pollution and lower emissions. China's move to the innovative development pathway could therefore promote a global transition to low-carbon development models.

Challenges for China's NDC Implementation

However, while there are substantial benefits from successful implementation of the NDC, there are also a significant number of challenges that will need to be overcome, as well as some key uncertainties. These challenges and uncertainties are both domestic and international, and there is no doubt that the ambitious mitigation targets of NDC cannot be achieved in the traditional development path. They must be effectively and carefully managed to avoid setbacks in reaching the new normal while recognizing that as a developing country, China has to balance the economic development needs and mitigation targets (whose only solution is economic transition). This section explores a selection of the challenges China must manage in its transition including the availability of technologies at low cost, a need to accelerate its low-carbon innovation capacity; the political economy and lock-in challenges posed by late stage industrialization; its natural resource endowment; transition costs, including the risk of stranded assets; and social costs.

Managing these challenges and risks will require effective policy measures and the development of new growth poles, while ensuring social cohesion. The section also discusses some of the key policy options that are available to overcome these challenges. At present, there are a number of cases where policy signals towards reducing emissions are in contention with other policy signals and drivers. One of the key challenges moving forward will be to move towards a more consistent and coherent policy package that supports NDC implementation. This will likely result in an increased focus and enhanced role for economic incentives that can provide signals for low-carbon entrepreneurial development and hence new growth policies. Such signals, supported by appropriate training, can provide a just transition for the Chinese workforce, particularly for those currently employed in the fossil fuel industry. It will remain crucial in designing all policies that they minimize adverse impacts on, and even improve, wealth distribution.

Availability of Technologies at Low Cost

Achieving the new normal relies on the availability of new technologies at manageable cost, which is currently highly uncertain. Some key low-carbon technologies are not currently widely available and cost projections are uncertain. For example, CCUS technology remains costly and is not widely deployed, particularly at a large scale. In addition, China needs to provide low-carbon electricity via renewables whilst maintaining reliable baseload electricity. Technologies associated with the integration of high penetrations of renewables have not yet been sufficiently demonstrated at the scale and cost being considered by China. Table 3.3 presents a technology roadmap, highlighting the wide range of technological advancements likely to be needed at different stages in order to achieve the targets set out in China's NDC and beyond.

Many of these technologies have high upfront costs and hence large financing requirements. For example, renewable energy technologies tend to have a higher share of capital cost as a proportion of total cost compared with traditional fossil fuel technologies. This is also the case for the infrastructure required to integrate these technologies into the grid, such as transmission and distribution systems. The continued availability of different forms of capital at an appropriate cost will be essential for financing these investments.

TABLE 3.3. China's NDC Technology Roadmap Shows That Rapid Advances in Low-carbon Technology Are Required

	Immediate Term (2010–2020)	Medium Term (2020–2030)	Long Term (2030–2050)
Power	Ultra-supercritical Large-scale onshore wind power generation Efficient natural gas-based power generation Third-generation large-scale pressurized water reactors Ultra-high-voltage power transmission technology Advanced hydropower technology	Integrated Gasification Combined Cycle Large-scale offshore wind power generation Advanced geothermal power generation Solar photovoltaic Second-generation biomass energy	Low-cost CCUS Fourth-generation nuclear power Concentrating solar power Solar nanotechnology photovoltaic Large-scale electricity storage systems for intermittent power supply Low-cost hydrogen fuel cells Smart grids
Steel	Coke dry quenching Pulverized coal-injection technology Negative energy-based steelmaking Residual heat and pressure recovery Energy management center Coal moisture control Combined-cycle power plant	SCOPE21 coking technology Smelting reduction technologies Advanced electric arc furnaces Hydrogen production from coke oven gas Waste plastic technology Ultra-thin Castrip Itmk3 iron-making technology	Low-cost CCUS technology
Transportation	Engine, transmission and vehicle technologies for better fuel economy in automobiles Advanced diesel vehicles Electrified railway Urban rail transport	Hybrid vehicles Information-based and intelligent transportation system High-speed railway	Fuel cell vehicles Efficient pure electric vehicles
Cement	Large-scale new suspension preheater kilns Efficient grinding Pure low-temperature waste heat power generation	Eco-cement Fuel substitution	Low-cost CCUS technology
Chemicals	Large-scale synthetic ammonia plants Large-scale ethylene plants Ethylene feedstock substitution	Fuel and feedstock substitution	Low-cost CCUS technology
Buildings	Light-emitting diode New building envelope materials and parts Energy-efficient appliances Combined heat and power cogeneration Solar water heater	Fuel and feedstock substitution Distributed energy systems Heat pump technology Combined cooling, heating and power systems Advanced ventilation and air-conditioning systems Low-cost and efficient solar PV buildings	Efficient energy storage technology Zero-energy buildings
General technologies	Frequency control technology Advanced electric motors	Frequency control technology Advanced electric motors	

An array of policy measures will be needed to encourage the development and deployment of these technologies at low-cost. This will include both technology specific policies and general broad-based policies to support low-carbon technology development such as the ETS. It will be important to pay particular attention to ensure that the complementarities between these policies are exploited and any overlaps or tensions are effectively managed. The country also needs to develop a responsibility sharing mechanism and an efficient and high-quality data and MRV system in order to support this technology development.

Technology Development and Innovation

Linked to the above, while China has made great progress in developing innovative low-carbon technology itself in recent years, it still needs to increase its pace to match global trends in the low-carbon technology revolution. Analysis of low-carbon technology intellectual property shows that China still lacks independent innovation ability in many core technologies. Table 3.4 sets out the top ten wind turbine patent owners in the world according to the Derwent Patent Index Database. There are no Chinese companies in the top ten despite China being the largest country for wind turbine manufacture and application. Table 3.5 indicates that the main owners of registered wind turbine patents in China, particularly wind turbine invention patents, are foreign companies.

In certain areas, such as thermal power units, some Chinese companies have caught up with developed countries but there are still a significant number of companies working with less developed technology. The thermal power industry is a clear example of this problem. China currently has 46 sets of the most efficient, 1,000 MW in production. This is more than the rest of the world added together. At the same time, there are a large number of laggard small thermal power units still running. During the 11th Five-Year Plan, China eliminated nearly 70 million kW of small thermal power units, and will eliminate a further 20 million kW during the 12th Five-Year Plan. However, Figure 3.3, which provides an overview of the installed capacity of different coal-fired units from the China Electricity Council, shows that around 10% of its installed capacity is from units with less than a 100,000 kW capacity.

TABLE 3.4. Top Ten Wind Turbine Patent Owners in the World

Patent Holder	Total Number of Patents	Country
General Electric Co	931	US
Vestas Wind Systems AS	690	Denmark
Siemens AG	449	Germany
Mitsubishi Jukogyo KK	321	Japan
Mitsubishi Heavy Ind Co Ltd	293	Japan
Wobben A	175	Germany
Repower Systems AG	173	Germany
Nordex Energy GMBH	142	Germany
Gamesa Innovation & Technology SL	137	Spain
LM Glasfiber AS	102	Denmark

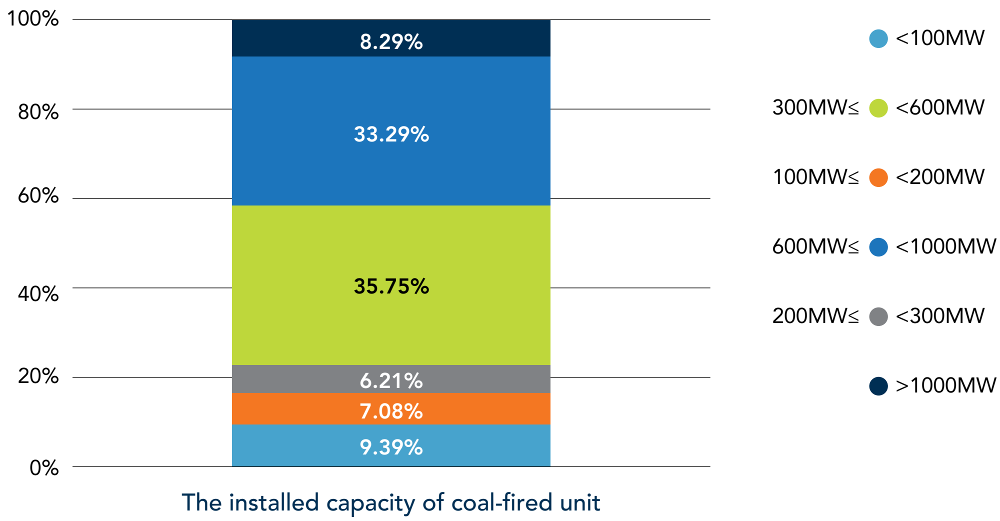
Source: Derwent Innovations Index, November, 2014

TABLE 3.5. Top Ten Wind Turbine Patent in China

Patent Proposer	Total Number of Patents	Total Number of Inventions	The Proportion of Inventions and Patents (%)	Country
General Electric Company	607	607	100	Foreign
Simens	269	257	95.54	Foreign
Vestas Wind Systems AS	171	166	97.08	Foreign
Mitsubishi Heavy Ind Co Ltd	154	154	100	Foreign
Guodian United Power Technology Company	154	75	48.7	China
Sinovel Wind Group Co.	138	31	22.46	China
Vestas Wind Systems AS	103	97	94.17	Foreign
Sanyi Electric Co.	100	54	54	China
Gamesa Innovation & Technology SL	75	75	100	Foreign
Mingyang Wind Power of Guangdong	73	40	54.79	China

Source: Derwent Innovations Index, November, 2014

FIGURE 3.3. The Installed Capacity Structure of Different Sizes of Coal-fired Units, 2014



Source: China Electricity Council

Chinese policy frameworks and institutions must be strengthened to allow for sufficient low-carbon technology development. At present, the relevant policies demonstrate a lack of top-level design, coordination and integration. In addition, the role of existing market mechanisms is ineffective and there is no business-led technology innovation strategic alliance. Changing this situation may require particular focus on developing strong political and economic institutions that provide sufficient incentives for creativity and innovation. Science and technology project evaluation mechanisms and results-sharing mechanisms can also be improved while the national RE subsidy fund remains undercapitalised. These institutional and policy obstacles represent important constraints that China will need to overcome in order to accelerate low-carbon technology innovation and reach its NDC targets.

Industrialisation and Urbanisation

China is in a transitional period, moving from the middle to late stage of industrialization. Currently China has a large proportion of high-energy consuming industries, high energy consumption per unit of GDP within these industries, and a higher level of energy consumption per product than the average level in major energy-consuming countries (IEA, 2014). According to World Bank statistics, in 2014, China's GDP accounted for 13.3% of global GDP, but it produced 49.6% of the world's crude steel; 65% of its electrolytic aluminium; 60% of global cement; 65% of building ceramics; 50% of flat glass; and 70% of chemical fiber (Wang, 2016). In 2014, China's energy consumption per unit of GDP was 409 tonnes of standard coal per US$1 million, far higher than the level of developed countries, and close to twice the world average (Ibid).[14] There is a chance that China could 'lock in' this high industrialised stage of development: existing practices, industries and infrastructure become institutionalised and embedded in the economy, making structural changes more difficult.

Alongside industrialisation, the trend of urbanisation could pose a challenge to achieving China's NDC. In 2015, the urbanization rate in China (for the resident population) was 56%, lower than the 70% rate in developed countries when their per-capita emissions peaked. The 'National Plan of New Urbanization (2014–2020)' envisages that by 2020 the urbanization rate of the resident population will reach 60% while the Development Research Center of the State Council estimates that it could reach 65% by 2030. This means that nearly another 3 billion people (or 20% of global urban population growth) are going to move into cities by 2020. China's new urbanization strategy aims for human-centred sustainable urbanization. Urbanization, industrialisation and existing development objectives such as poverty eradication, are all likely to increase energy demand and economic growth, and thus all pose possible hurdles to meeting China's NDC.

Natural Energy Resource Endowment

A central hurdle to low-carbon development in China is the natural abundance of coal reserves. In 2014, coal accounted for 66% of China's primary energy consumption, far higher than the world average of 30%, and with a significant further gap to the OECD average of 19.1% (BP, 2015). China's coal consumption accounted for 50.55% of the world's total, higher than its percentage contribution to global emissions. By contrast, in 2014, nonfossil energy accounted for 11.2% of China's primary energy, illustrating that the gap between the 2020 target of 15% and 2030 target of 20% is still large (Wang, 2016).

To achieve the NDC targets China will need to replace coal with clean energy sources. This could include natural gas. However China's natural gas reserves account for only 1.8% of the world's total, and its per-capita consumption of natural gas is less than 0.5 tonnes of standard oil. A transition to natural gas would also face challenges in terms of financing the required large-scale infrastructure and ensuring geopolitically secure gas supplies. In 2014, natural gas net imports in China were 55.7 billion m^3, meaning that China was dependent on foreign supply for 30.6% of its consumption.

This will require the development of a coherent policy package that supports not just investment in renewable energy, but also its sustained use. According to data from the National Energy Administration (2016), at the end of 2015, China's installed photovoltaic (PV) capacity was 43.18 million

14 The average global level is 238.9 tonnes of standard coal/US$1 million; the EU level is 124 tonnes of standard coal/US$1 million; the US level is 188.5 tonnes of standard coal/US$1 million; and Japan is 141.1 tonnes of standard coal/US$1 million.

kW, the highest in the world. In 2015, it added 15.13 million kW, more than one-quarter of the world's newly added capacity during that year. However, accompanying the rapid growth of PV power capacity, the average annual operating hours of national PV power generation declined to 1,133 (National Energy Administration, 2016). This is partly due to the phenomenon of abandoning PV power in the northwest of China. The annual average number of utilization hours in Gansu province is 1,061, and the abandonment rate is 31%. Similarly, the annual average utilization hours in Xinjiang province is 1,042 hours, and the abandonment rate is 26% (National Energy Administration, 2016). Similarly, is estimated that some provinces in China are currently curtailing 15–25 percent of wind power output[15] Reform to the power system to provide appropriate signals for optimizing the mix of power generation technologies, supported by institutions that ensure that these signals are consistently transmitted to all parties, as well as appropriate incentives for investment in power sector infrastructure, will be essential to overcome these barriers.

Transition Costs

China will incur 'structural' costs in achieving its NDC targets. Some low-carbon investments can bring economic returns, but others will bring considerable economic costs. Modelling performed by Renmin University of China (as described in Annex D) indicates that the incremental cost for realizing an emissions target of peaking emissions by 2030 and returning to the 2010 emissions level by 2050, will be US$86 billion in 2020 with a per tonne CO_2 mitigation cost of US$27. This amounts to 1.2% of GDP, implying an average cost per household of US$182 per year. In 2030 the incremental cost could reach US$269 billion at an average mitigation cost of US$56/tonne CO_2. This would account for 2.2% of GDP at an average of US$538 per household/year.[16] As noted in section 2.5.4, there is likely to be scope to use CGE models to gain a more up to date estimate of the possible costs of NDC implementation. This represents an important area of potential future research.

A big challenge is likely to be the sunk costs of existing high-carbon infrastructure both in China and overseas. A large amount of financing has already been devoted to existing carbon intensive installations. This means that there is a high incentive to allow this infrastructure to continue, rather than paying the up-front costs for new installation. Whether the NDC targets can influence these investment and operational decisions will have a large bearing on the ability to achieve the low-carbon transition in the long term.

Alternatively, policy makers and/or market forces might threaten the early retirement of these assets causing significant socioeconomic stresses (see also section 3.2.6). Early retirement could lead to losses and bad debt for mining and power companies, as well as structural unemployment. Notably, the stimulus of these stresses may not only be domestic: If increasing levels of ambition of climate policies around the world combined with decreasing costs of renewables, then it is plausible that Chinese debt and equity financing for high carbon assets in, for example, other countries in Asia, Africa and Eastern Europe, could yield much lower returns than expected.

Domestically, these challenges are likely to be particularly acute in the power sector. In the power sector, thermal power installed capacity rose by 204 million kW between 2011 and 2014, 86% (175 million kW) of which was new coal capacity. The total installed capacity of thermal power that has been approved

15 Canbing Li et al., "Comprehensive Review of Renewable Energy Curtailment and Avoidance: A Specific Example in China," *Renewable and Sustainable Energy Reviews* Vol 41 (2015): 1067–1079, doi:10.1016/j.rser.2014.09.009.

16 The costs are 2005 constant prices. The data source is the simulation results of the Energy Technology Optimization Model of Renmin University of China, and is published in 'China Human Development Report 2009/10: China and a Sustainable Future Towards a Low Carbon Economy and Society', which is jointly published by UNEP China and Renmin University of China. The report's emissions-reduction scenario is close to China's NDC target as its emission peak year is also 2030. For that we quote the scenario results herein as a reference of China's NDC targets.

but is yet to be built before 2020 is 200 million kW (157 million kW coal-fired and 42.58 million kW gas-fired installed capacity). The maximum power generating load in 2014 was 797.29 million kW, while the total installed capacity was 56% higher at 1.37 billion kW. By contrast, total installed capacity in developed countries is usually around 30% of maximum load. China's power supply capacity is far higher than its demand. That means that despite electricity demand growth slowing, thermal power installed capacity, especially coal, is still rising rapidly. In the context of the NDC goals, this is potentially risky investment that takes up economic resources, reduces the overall efficiency of the power sector, and exacerbates the abandonment of wind and solar power.

Addressing these challenges and avoiding blind investment in high-carbon infrastructure, requires integration of the NDC target into investment frameworks and a stronger role for market-based measures. The NDC should be used as a basis for forming an implementation road map, assessing infrastructure demand in the future, setting the appropriate access thresholds, and implementing macro-control policies. There can also be an important role for market based measures, including carbon pricing, in supporting the appropriate investment decisions, although it will be important for the structure of the energy sector to be conducive to allowing the carbon price signal to be effective. They may also need to explicitly identify how the costs and risks of high carbon asset write-downs will be shared between industry, financiers and the government.

Social Costs (e.g. Structural Unemployment)

Achieving China's NDC will significantly impact traditional high-energy industries. During the 11th Five-Year plan, 7,000 small units in China's power industry were shut down, involving nearly 40 million staff (People's Daily, 2016). China has recently proposed supply-side structural reforms and identified the five key tasks: addressing overcapacity; reducing inventory; deleveraging; lowering costs; and bolstering areas of weakness. This reform process will inevitably have employment impacts, particularly when reducing excess coal capacity.

As shown in section 3.1 jobs created through low-carbon industries might exceed those that will be lost in the transition. However, employment in emerging industries may not require the same skills those who lose their jobs in high-carbon industry possess. This is the 'structural unemployment' problem. Most of those facing the risk of unemployment have less education and fewer skills, and may find it difficult to complete a career transition quickly. This can cause challenges for the transition process. This is particularly an issue if there are a large number of local workers in a geographic area as it can create local fiscal expenditure difficulties. To achieve a smooth and just transition the Chinese government should focus on re-skilling, retraining and finding suitable new positions for affected workers as well as creating a flexible open business environment in which new low-carbon businesses can thrive.

Uncertainties

While challenges are inherent in reaching emissions reductions, there are also uncertainties in discerning the underlying trends that will influence low-carbon development. To manage this uncertainty China needs to integrate low-carbon strategies and objectives into its overall national development strategies. It also needs to formulate a clear low-carbon policy framework; maintain continuity and policy stability; and form stable market expectations and communicate these to all stakeholders in the low-carbon technology innovation system. This section highlights some of the key uncertainties that China must manage.

Uncertainty in GDP Growth

China has maintained an average annual GDP growth rate of over 10% between 1990 and 2010, and around 7% in recent years, despite the economic slowdown. It is generally expected that China will change to a stage of medium–high economic growth in the next decades, as a result of entering the new normal. However, the length and strength of economic growth in this development stage is unclear. The rate of GDP growth over time will be dependent on both domestic and international forces, as well as government policies.

Uncertainty in Population Growth.

Population acts as a major driver of energy consumption and emissions. China's already substantial population is expected to increase further in the next 15–20 years, 1.37 billion as of 2014 (NBS, 2016). It has recently adjusted its family planning policy to allow all couples to have two children legally. It is unclear what impact this policy adjustment will have on the size and peaking of the population, especially considering the large population base. The future rate of urbanisation is also unclear. These factors all serve as uncertainties for China's future energy consumption and emissions.

Uncertainty in Service Demand Control

Service demand is a decisive factor affecting expected energy consumption in the transportation and building sectors. If not properly guided, service demands of buildings and transportation will increase enormously and drive up energy consumption and emissions. A key challenge lies in the reasonable control of service demands while meeting people's needs to improve their living standards during the urbanization process. By enhancing the carbon-mitigation effort, energy consumption per unit of building area can be reduced to about one-half of the current level of developed countries; the per-capita housing area will reach approximately the level of major EU countries; and car ownership per 1,000 persons will be less than one-half of the current level in Japan and one-third of the US. All these targets are difficult to achieve in the absence of appropriate guidance and incentives for low-carbon lifestyles and other institutional, policy and market management.

Uncertainty in the Decline of Energy Intensity

Small changes in the rate of energy intensity decline will have a significant impact on emissions. Energy intensity has declined significantly since the 11th Five-Year Plan period as a result of the introduction of energy-saving technologies and the elimination of backward production capacity. As the potential of technical progress in improving energy efficiency shrinks, industrial restructuring and upgrading will play the leading roles in reducing energy intensity in the future. With appropriate efforts, an annual decline in energy intensity of 3–3.5% during 2010–30 is achievable. However, if the annual decline shrinks by 1 pps, national energy demand will exceed 7 Gtce, and carbon emissions will exceed 13 $GtCO_2$ in 2030.

Uncertainty in the Development of Non-Fossil-Fuel Energy

The rapid development of nonfossil energy is essential for the continued decline in carbon intensity in energy consumption, and will contribute significantly to carbon-mitigation potential. If the share of nonfossil fuel energy increases by 1%, with all of the increase replacing coal consumption, about 0.17 $GtCO_2$ can be cut by 2030, and the carbon intensity per unit of energy consumption can be cut by 1.4%. Likewise, if the share of nonfossil fuel energy increases by 1% by 2050, about 0.19 $GtCO_2$ can be reduced, and the carbon intensity per unit of energy consumption can be reduced by 1.7%. However, there are many challenges influencing the high-speed development of nonfossil fuel energy. For wind and solar energy, although the resources and application potential is large, barriers to large-scale use include the need for long-distance transmission, grid stability, energy storage capacity, and the high investment costs associated with infrastructure construction. The development of nuclear power also faces uncertainty, including security, the management of nuclear waste, the speed of construction, and public concern. All these challenges create significant uncertainties for the decarbonization of the Chinese energy system.

Uncertainty in the Deployment of CCUS Technologies

Current analysis indicates that CCUS development still faces many challenges relating to strategic policy, financing, and technology. In terms of international and domestic strategies, no consensus has yet been reached regarding its use within international negotiations on climate change, and an international platform for CCUS cooperation has not yet been set up. CCUS demonstration projects are subject to substantial funding gaps, and stakeholders hold differing views over the appropriate role for CCUS. Moreover, research on the necessity of the carbon transportation network has only just started while assessments of carbon-sequestration potential and risk response research in China need to be undertaken. Carbon-capture costs vary between sectors due to differences in CO_2 concentrations and capture areas but are currently around US$15–75 and US$25–55 per tonne of CO_2 in the power and industrial sector, respectively.

An International Perspective on China's Innovative Development Pathway

SUMMARY

China's innovative development pathway will result in China peaking its emissions at a lower development and GDP per capita level than any OECD country has. While this partly reflects the increased global availability of low-carbon technologies, China's innovative development pathway will thus represent a historical precedent that other developing countries could replicate.

China's innovative development pathway will also result in lower cumulative emissions per capita than developed countries achieved. Its current profile in emissions sources reflects that of a developing country, but this will likely shift with the transition to the new normal.

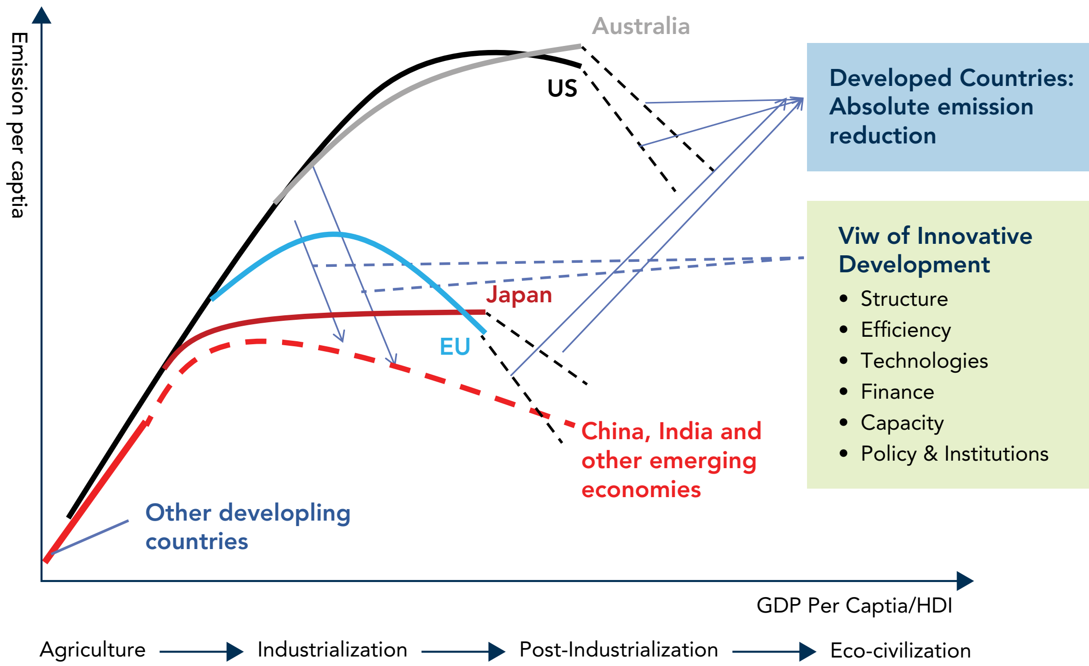
Both the EU and Japan provide important examples of advanced industrialised economies that have peaked at relatively low emissions per capita. These examples demonstrate that China's approach to decarbonization is compatible with reaching a high-income status.

In order to understand why China's innovative development pathway is a new and important example, it must be placed in an international and historical perspective. This chapter examines how the implementation of China's NDC and innovative development pathway compares to the development experiences of OECD countries. In particular, it identifies what precedents the country will set if it is successful and what it can learn from the experiences of others.

China's Innovative Development Pathway in an International Historical Perspective

Although care should be taken to allow for the different historical contexts, the concept of the innovative development pathway has been distilled from trends of the industrialization process in developed countries. In advanced developed countries (e.g., US, Canada, Australia), the relationship between economic growth and emissions per capita has typically taken an inverted U shape: emissions per capita first rises as GDP per capita increases, before falling after a certain level of development is achieved. This is commonly referred to as the environmental Kuznets curve and is shown in stylized form in Figure 4.1.

FIGURE 4.1. Development and Emissions: A Kuznets Curve?



Source: Natural Resources Defense Council, 2016.

This conception of the trajectory of emissions over time and through development highlights important differences between developed and developing countries. Developed countries, having moved through industrialisation and urbanisation to a post-industrial stage and sitting on the right hand side of the environmental Kuznets curve, share a number of common characteristics:

- Being at the top of the global value chain, increases in factor efficiency contribute more to their economic growth than increases in factor input;
- The domestic economy is dominated by nonenergy intensive industry and services;
- Most infrastructure has been already built and the pace of 'decarbonization' is partly constrained by the cost and challenge of retrofitting.

The picture is different in developing countries which are still in, or have yet to start, the process of industrialization and urbanization and remain on the left-hand side of the environmental Kuznets curve. Their common characteristics include:

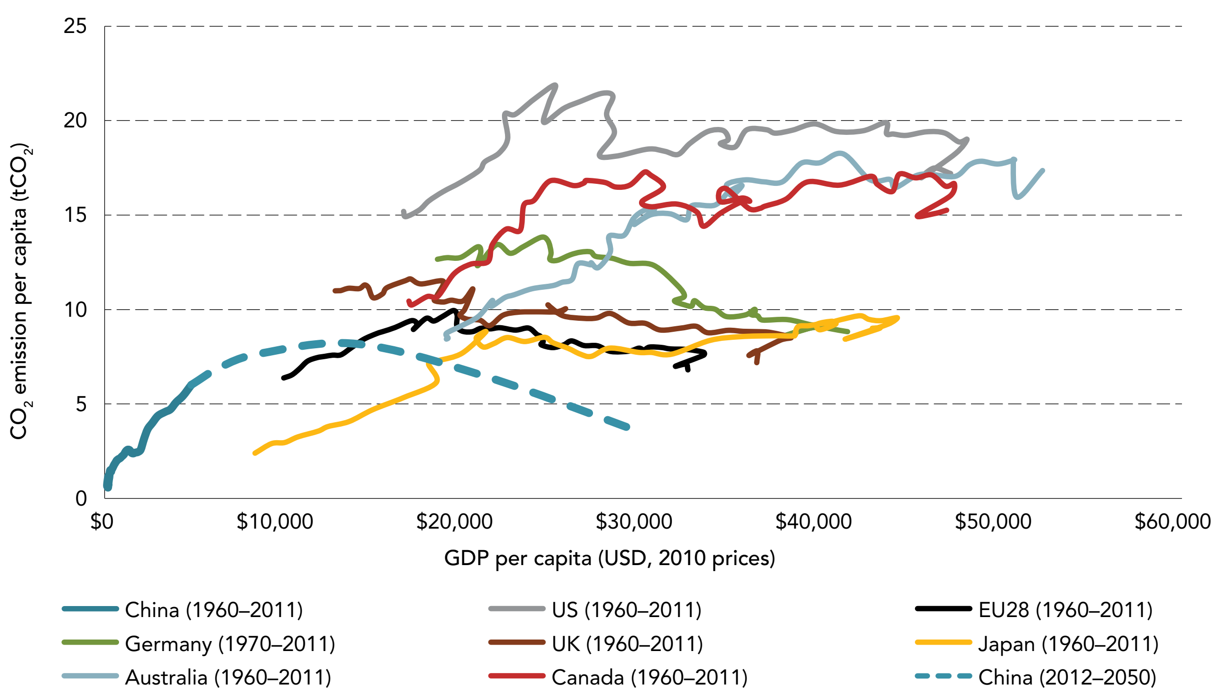
- High future need for infrastructure investment;
- Heavy industries dominating the domestic economy;
- Dynamic urban sprawl which increases the demand for modern transport infrastructure;
- Increasing energy demand driven by the necessity of fulfilling basic needs of a large (sometimes dominant) part of the population.

Low-carbon development raises different issues for developing and developed countries. For example, due to a later start and lack of infrastructure lock-in, developing countries have a clear opportunity to skip the traditional development model and instead pursue a different and beneficial low-carbon development trajectory. Conversely, developed economies have an opportunity both to support the alternative development models of developing countries and provide examples of best practice sustainable development. There are also challenges that are common to all countries. For instance, developed and developing countries alike will need to lower their energy intensity per unit of GDP and seek decarbonization of the energy structure.

Imposing China's NDC on the standard environmental Kuznets curve shows a peak earlier than typical in developed countries. As depicted in Figure 4.2, with extra detail in Table 4.1, peak emissions will occur at a GDP per capita of around 33% lower than in OECD countries, and at an emissions per capita level of around 30% lower than in OECD countries. This partly reflects the efforts that China expects to make, as well as the greater availability of low-carbon technologies that are now available globally.

Developed countries have peaked at different rates and followed different reduction trajectories. The US, Canada and Australia reached a peak of around 20 tonnes of CO_2 emissions per capita, compared with around 10 tonnes for the EU and Japan. These differences in peaking suggest that it is possible to achieve a similar per-capita income level with much lower per-capita CO_2 emissions. In the European Union and the US, per capita fossil fuel related CO_2 emissions (CO_2 emissions in Figure 4.2 below) peaked when per capita GDP reached between USD17,000–25,000 (in 2010 prices), while for Canada, Japan and Australia, per capita CO_2 peaked with GDP per capita as high as USD30,000–40,000 (in 2010 prices). The average for OECD countries was around USD21,000. In contrast, projections based on China's NDC targets show that China's per capita emissions peak will occur when per capita GDP is only around USD14,000. The US, Canada and Australia saw peak emission values of 20 tonnes of CO_2 per capita, while the European Union and Japan had peak values around 10 tonnes per capita. The OECD average was around 11.5 tonnes per capita. China's expected peak emissions are expected to be lower than this, at 8.2 tonnes per capita.

FIGURE 4.2. A Comparison of Kuznets Curves Between China and OECD Countries



Note: Includes only energy-related CO_2 emissions.

Source: Historical CO_2 emissions data from 1960 to 2012 is from CDIAC. Population and GDP data is from the World Bank. Data after 2012 is calculated based on NDC targets.

TABLE 4.1. GDP and Emissions per Capita at the Peak Year

	GDP per Capita at Peaking Year (2010 prices)	Fossil Fuel Related CO_2 Emissions per Capita – Peaking Level (tCO_2/person)
OECD	$21,075	11.50
Annex I Countries	$18,018	12.66
EU 28	$19,414	9.95
EU 15	$23,524	9.79
US	$25,085	21.88
Japan	$42,086	9.67
Australia	$41,108	18.25
Canada	$30,043	17.27
Germany	$24,301	13.82
UK	$17,030	11.62
France	$23,337	9.54
China	$14,026	8.18

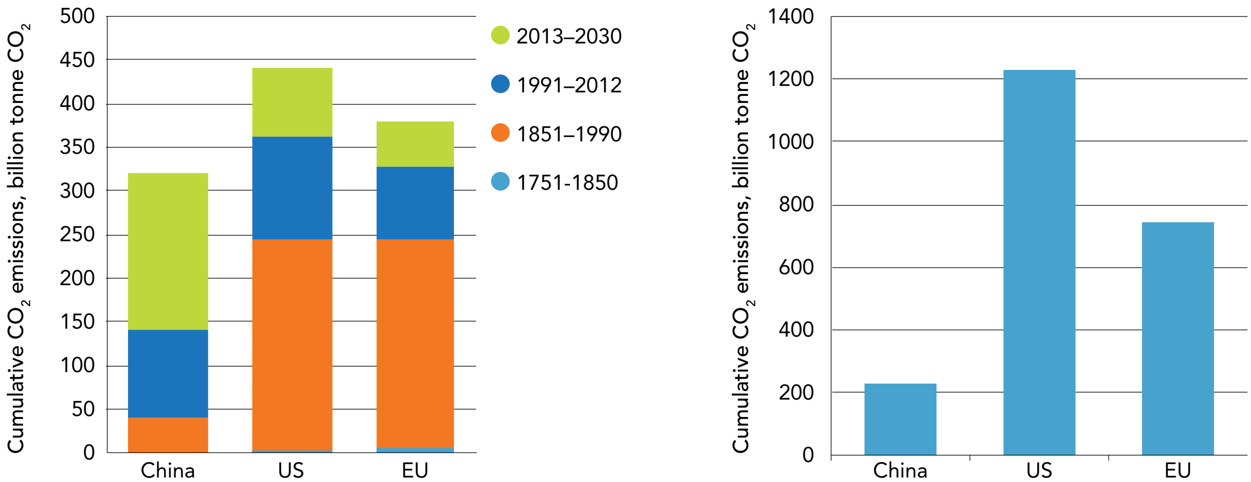
Source: CDIAC (2015) and World Bank database (2015); China's data from an NDC scenario from PECE model developed by NCSC and Renmin University of China.

International Comparisons of Emissions and Development Trends

Understanding the challenge of the innovative development pathway can be helped by an understanding of how China currently and historically compares to other major emitters. This section will provide such a comparative analysis across a range of criteria including sources of emissions, production and consumption emissions, and cumulative emissions. Figure 4.3 compares the cumulative emissions of the US, Europe and China. Cumulative emissions have grown steadily in the US and Europe since the 1850s, maintaining a steady trend throughout this period and only beginning to slow down after 2013. China's cumulative emissions began to increase significantly since 1991, and its annual emission growth rate accelerated after 2013. In 2012, the total cumulative emissions of the US and Europe since 1750 were around 5 times those of China; in 2030, the multiple is estimated to be about 2.6.

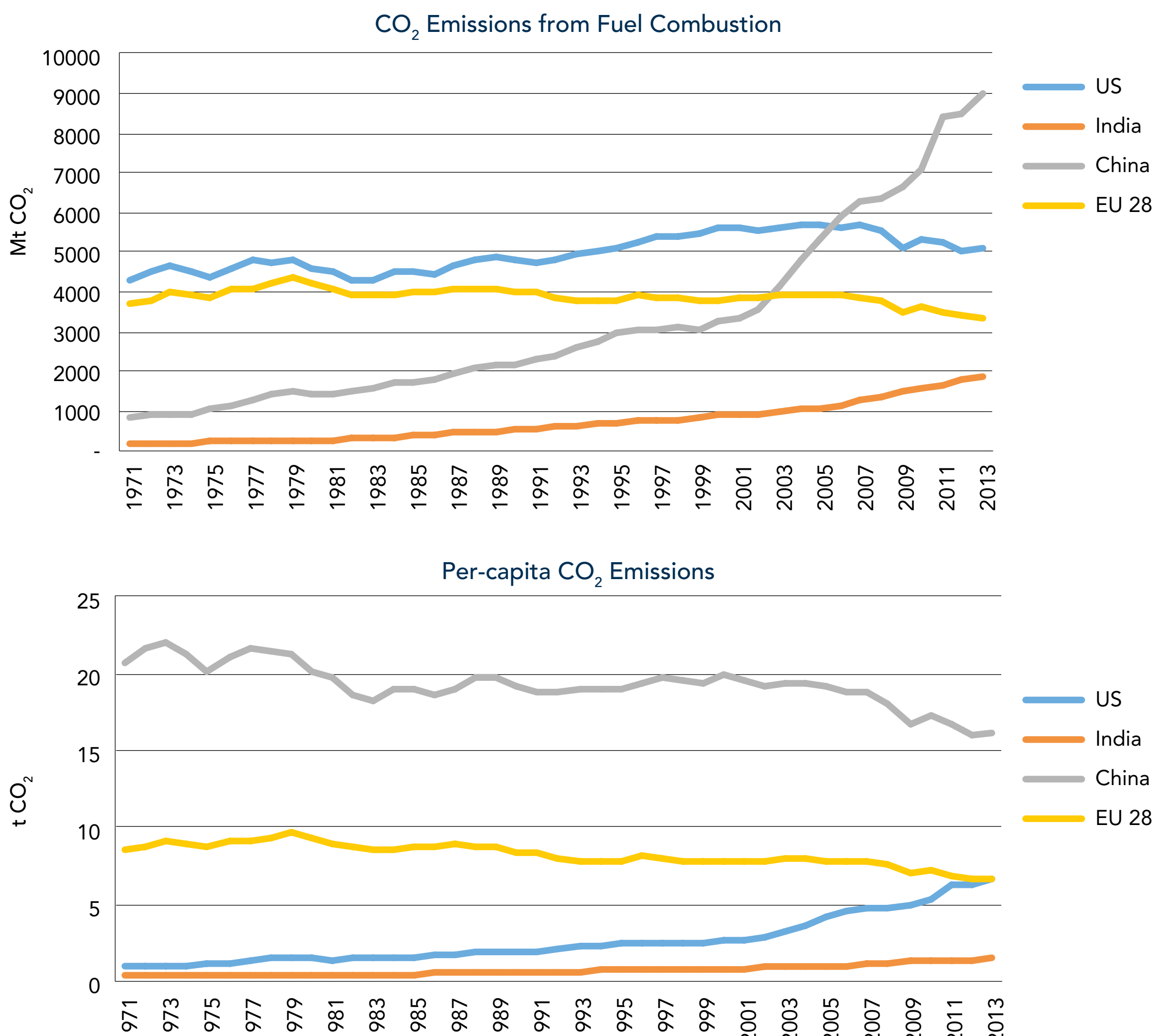
China's per capita cumulative emissions could remain below that of major emitters if the innovative development pathway is successfully implemented. Looking at the per capita cumulative emissions level between 1751 and 2030, China will account for around 200 tonnes, Europe 770 tonnes (3.9 times that of China) and the US 1,200 (6 times that of China). Figure 4.4 compares historical trends in per capita emissions and energy related emissions for different major economies. This demonstrates that whilst China's absolute emissions have reached unprecedented levels, its emissions per capita is expected to remain below other major emitters.

FIGURE 4.3. Cumulative CO_2 Emissions in China, the US, and EU



Data sources: Contains only energy-related CO² emissions. Data of historical CO² emissions from 1751 to 2012 are drawn from CDIAC. Population and GDP data are from the World Bank. Data after 2012 is calculated based on NDC targets of each country.

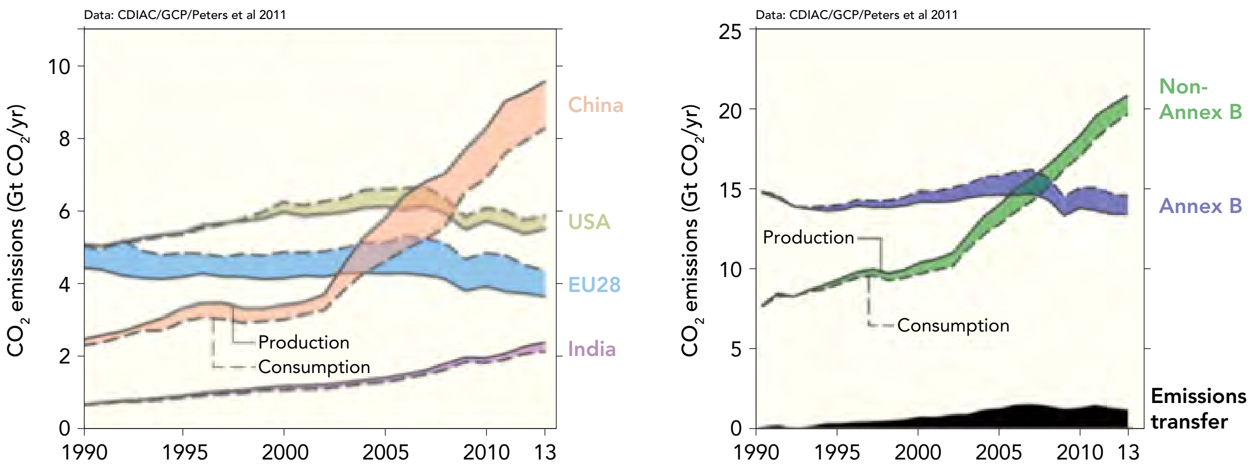
FIGURE 4.4. Historical Trends in Energy and per Capita CO_2 Emissions



Data source: IEA, CO_2 emission from fuel combustion 2015.

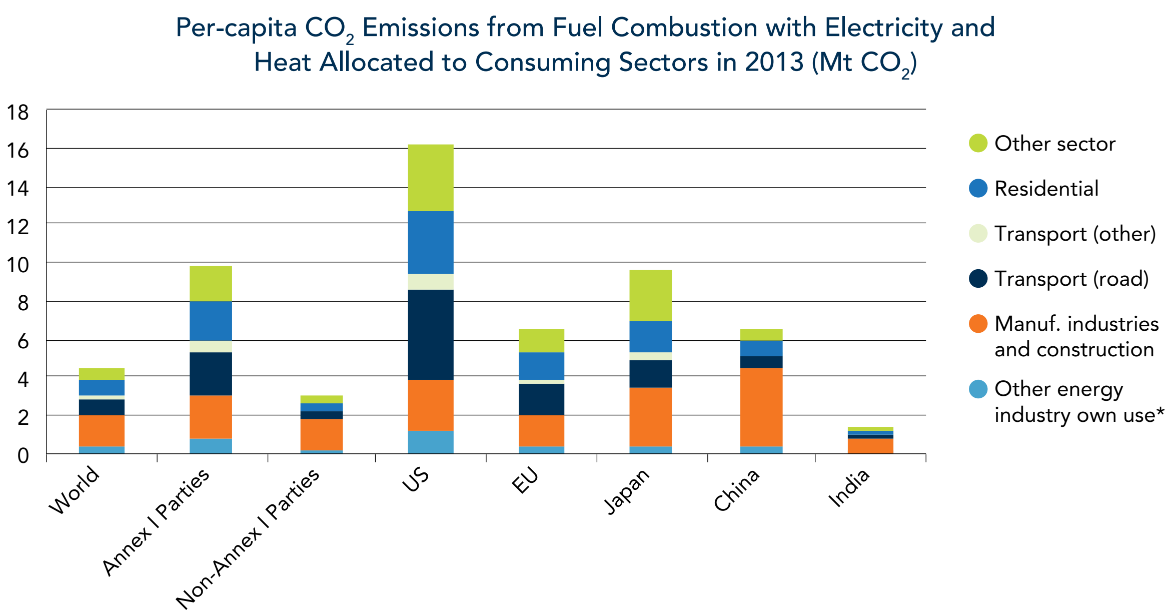
While the production based emissions of the early industrialized countries has begun to decrease, their consumption based emissions have continued to grow, with the gap between the two becoming increasingly significant. The opposite trend is apparent in developing countries, who have become the workshops for many emissions intensive goods and services. This reflects a new global economic pattern where industralisiation has become concentrated in emerging economies. Figure 4.5 shows this gap between production and consumption in developed and developing countries. Figure 4.6 shows the emission per capita profiles of a range of consuming sectors across both developed and developing countries. In implementing the innovative development pathway, China will need to take account of these trends.

FIGURE 4.5. A Comparison of Consumption and Production Emissions



Source: Global carbon budget 2015

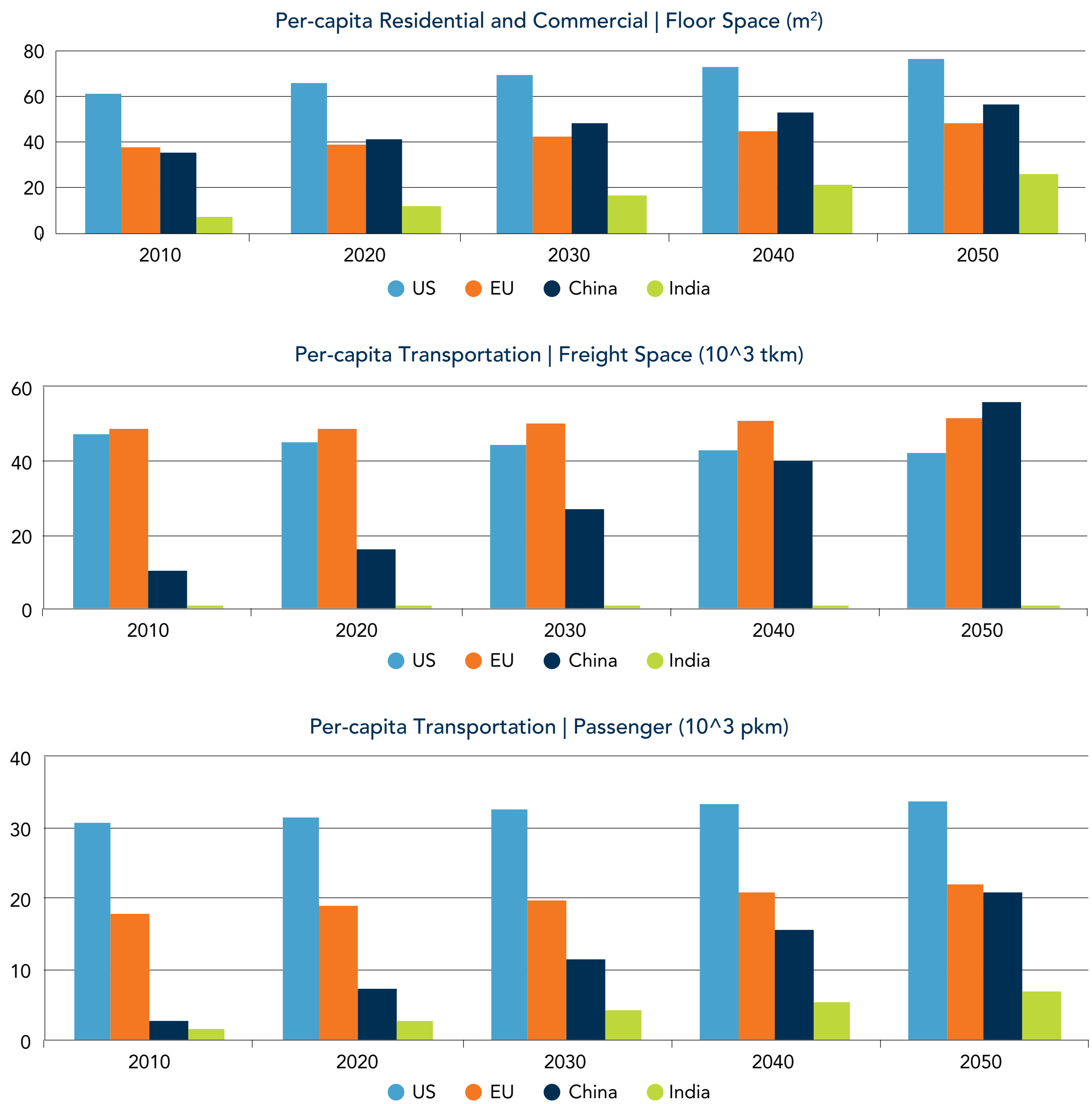
FIGURE 4.6. Per Capita CO_2 Emissions from Fuel Combustion with Electricity and Heat Allocated to Consuming Sectors in 2013 ($MtCO_2$)



Data source: IEA, 2014..

The source of emissions from the energy sector varies across countries. Emissions in the US, EU and other developed countries are mainly from transportation and other service oriented industries. Emissions in China, India and developing countries typically come from the manufacturing and construction industries or other secondary industries. In developed countries, transportation emissions account for a large proportion of total emissions. Traditional transportation infrastructure and long-lasting consumer habits have resulted in a lock-in effect. By contrast, the per capita emissions levels of the transportation and building sectors in developing countries are relatively small, both in absolute terms and as a share of global emissions, although the average annual growth rate is faster, especially in China (see Figure 4.7). With the transition towards the new normal China can expect a shift towards emissions sources that are more closely aligned with the current profile of developed countries.

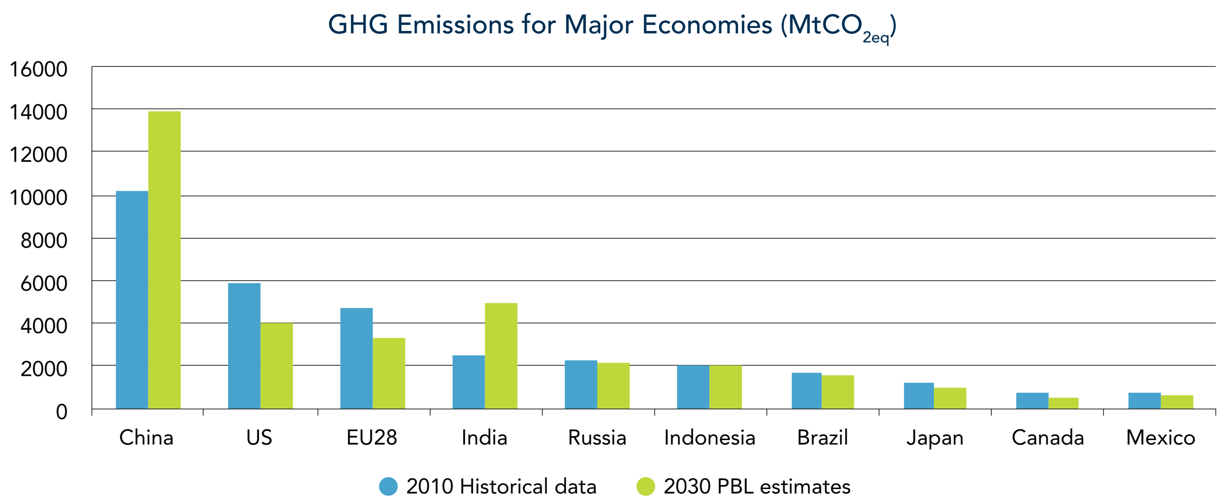
FIGURE 4.7. Per Capita Energy Service Demand Comparison

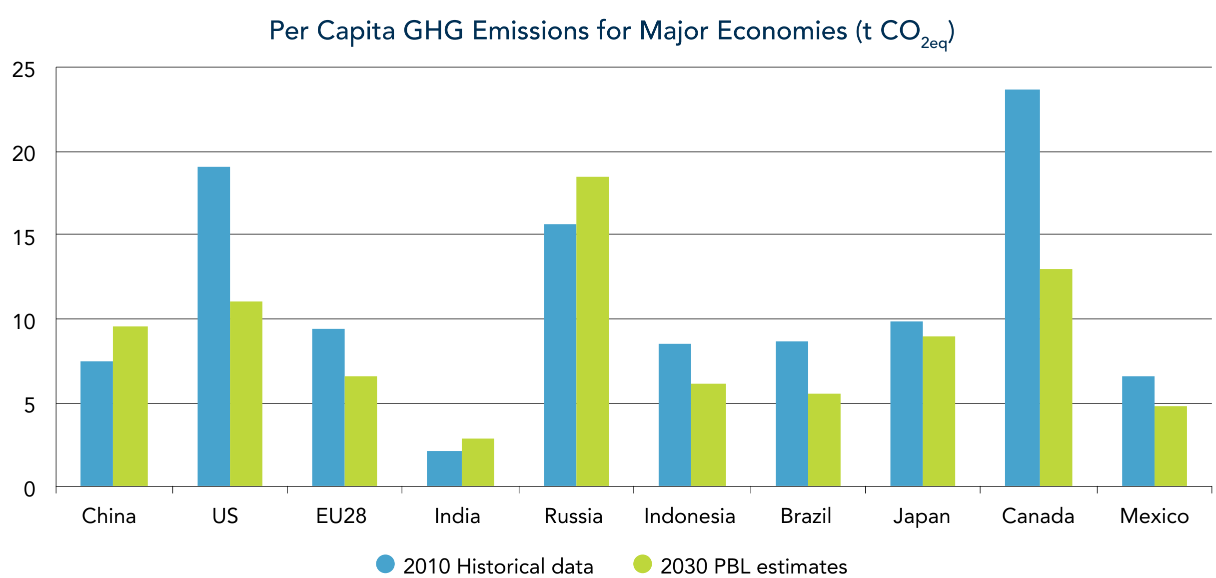


Data source: Scenario review median values

China is looking to undergo deep emissions reductions at relatively low per capita GDP levels, although there is a historical precedent for this in Japan and the EU (figure 4.8). In the NDC scenario, using per-capita GDP (2010 US$, constant prices) as an indicator, China's economic development scenario in 2020 is roughly equivalent to the development status in Japan in the early 1960s. In 2020 China's per capita emissions will be around 7.67 tonnes compared with 2.39 tonnes for Japan in the early 1960s. China's level of economic development in 2030 is expected to be roughly equivalent to that of Japan and the EU between 1965 to 1970. However, in 2030 China's per-capita emissions will be approximately 8.18 tonnes (energy-related CO_2), while per capita emissions in Japan and the EU between 1965 and 1970 were 4.70 tonnes and 7.97 tonnes, respectively. Comparing China (in the NDC scenario) against the 'historical equivalent development period' of developed countries, China's per capita emissions level will be comparable with that of the EU. Further reductions will be needed to reach Japan's historical equivalent per capita emission level. This suggests that China's innovative development pathway is feasible.

FIGURE 4.8. Top 10 GHG Emitters in 2010 and 2030 and per Capita Emissions





Data source: Historical GHG data for Annex I countries are based on UNFCCC inventory submissions including LULUCF; data for non-Annex I countries are based on PBL best estimate.

This international comparative analysis holds many lessons for China's innovative development pathway. First, assisted by the global availability of low-carbon technologies, China could create a precedent by peaking at an earlier stage of development and income per capita than OECD countries have. Second, Japan and Europe have peaked at similar emissions per capita levels, suggesting that the transition is feasible. Third, China's cumulative emissions and cumulative emissions per capita could remain lower than other major emitters if the innovative development pathway is successfully implemented. Fourth, China's emissions sources profile currently reflects its emerging economy status, but this will likely change over time to more closely align with the profile of developed countries. Thus, while China can learn from the experiences of developing countries, its innovative development pathway will be treading new ground internationally in low carbon development.

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Annex A: China's Pre-NDC Emissions Reduction Efforts

SUMMARY

China has incorporated climate change into its national strategic planning, including FYPs.

A range of legislative, executive, economic and market-based tools has been put in place to implement the response. China is expanding its international cooperation on energy and climate issues.

China has made notable progress to date, and by 2014 was approaching or had already exceeded its key 2015 targets.

Progress to Date

China has accelerated the incorporation of climate change into its national strategic planning over the last decade. Former President Hu Jintao's speech to the G8+5 in 2005 stressed that climate change and environmental policies are a central pillar of development planning. China has already put this into practice in a number of ways:

- The *2006 Eleventh FYP* set mandatory energy saving and emissions reduction targets for the first time;
- The 2007 *Report to the 17th National Congress of the Communist Party of China (CPC)* promoted environmental conservation and energy and resource efficiency as a requirement for economic development;
- The 2010 *Twelfth FYP* included the promotion of green development and low-carbon development;
- The 2011 *Report of the 18th National Congress of the CPC* recommended incorporating climate change and sustainability into all aspects of economic, political, cultural and social planning;
- The 2015 *Opinions on Accelerating the Building of Ecological Civilisation*, published by the Politburo of the CPC Central Committee, established that China should prioritize energy savings and environmental conservation and regeneration as core development policies. It also noted that ecological progress and innovation are key pillars of development.

China's commitment to a low-carbon 'ecological civilization' future is also evident in its adoption of near-term climate change targets.

The importance of sustainable development and climate change is reflected in detailed short-term targets for 2015 and 2020 for reducing energy consumption, increasing energy

efficiency and rolling out renewable energy electricity generation. The 2010 *Twelfth FYP* was the first planning document to impose mandatory targets for the energy and carbon intensity of economic activity, and also included targets for the share of fossil fuels in energy consumption and for total energy consumption. These objectives have been further developed by the *Energy Development Strategy Action Plan (2014–2020)*, which includes targets to cap annual primary energy consumption and annual growth rates of primary energy consumption, alongside fuel mix and generation targets.

China is progressing towards fulfilling these targets and in some cases has already exceeded them. By 2014 the energy intensity of GDP had fallen by 13.5% against a 2010 baseline, while the installed capacity of renewable energy had increased by more than 70% from 2010 levels. In 2014, both the share of renewables in installed capacity and power output from renewable energy had already exceeded the 2015 targets. In 2015, energy consumption per unit of GDP had fallen by 19.71% relative to the 2010 level, and CO_2 emission per unit of GDP reduction is 21.73%, surpassing the FYP targets. Table A.1 lists China's progress in meeting key 2015 climate change targets. The period of the *Twelfth FYP* has been successful in promoting low-carbon development and achieving climate objectives (Table A.2). Table A.3 provides an overview of the different policies that have been used to achieve progress to date.

TABLE A.1. China Progress Towards Meeting 2015 Targets

Outcome	2015 Target	Progress to 2014
Energy consumption reduction per unit of GDP relative to the 2010 level	16%	13.5%
CO_2 emissions reduction per unit of GDP relative to the 2010 level	17%	16.2%
Share of nonfossil fuels in primary energy consumption	11.4%	11.2%
Share of renewable energy installed capacity	30%	31%
Share of renewable power output	20%	22%
Hydropower installed capacity	260 million kW	300 million kW
Connected-grid wind power installed capacity	100 million kW	96 million kW
Nuclear power installed capacity	40 million kW	20 million kW
Connected-grid solar power installed capacity	21 million kW	26.5 million kW

TABLE A.2. Targets and Achievements During the *Twelfth FYP* Period

Index	Target (2015)	Achievement
Energy consumption reduction per GDP based on the 2010 level (%)	16	19.71
CO_2 emissions reduction per GDP based on the 2010 level (%)	17	21.73
The share of nonfossil fuels in primary energy consumption (%)	11.4	12
Forest coverage (%)	21.66	21.63*

**Bulletin on China's Environment Status 2015.*

TABLE A.3. A Sectoral Overview of China's Pre-NDC Mitigation Policies

	Policies
Energy	The upgrading of thermal power The promotion of renewable energy
Industry	Implementation of target-oriented responsibility system for energy saving Energy saving and low-carbon action for 10,000 enterprises Shutting obsolete factories Energy performance contracting program
Transport	Demonstration and popularization of energy saving and new energy vehicles Elimination of outdated vehicles The update of fuel consumption ceiling of vehicles
Building	Implementation of mandatory energy saving standards of building Retrofitting energy saving of existing buildings The upgrading of heating supply system Energy saving products

Programs and Policies to 2020

China has already established a detailed policy framework to structure its response to climate change up to 2020. The 2014 *National Plan on Climate Change (2014–2020)* identifies guiding principles, main goals and targets, a road map, and policy directions for addressing climate change. Key objectives include adjusting China's industrial structure; improving energy conservation and efficiency; optimizing the structure of the energy sector; controlling emissions from nonenergy activities; and increasing carbon sinks. The *National Plan* also outlines continued low-carbon and emissions trading pilot programs, and sets out plans for building capacity, scientific understanding, and data to support climate change policy making.

The key target for 2020 is to reduce the carbon intensity of economic activity by 40–45% compared with 2010. Table A.4 presents China's other key energy related 2020 targets. These are in addition to a target to cap total primary energy consumption over the entire thirteenth FYP period at 4.8 billion tonnes of coal equivalent (tce). To help achieve these economy wide targets, China has also established sectoral targets to increase energy and carbon efficiency in the industrial, construction and transport sectors. These sectoral targets will further help to shift the structure of the economy towards a less energy-intensive mix of activities and increase forest coverage. These 2020 sectoral targets are summarized and shown in Table A.5.

TABLE A.4. China's 2020 Energy Targets

Outcome	2020 Target
CO_2 emissions reduction per unit of GDP based on the 2010 level	40–45%
Share of nonfossil fuels in primary energy consumption	15%
Hydropower installed capacity	350 million kW
Connected grid wind power installed capacity	200 million kW
Nuclear power installed capacity	58 million kW
Connected grid solar power installed capacity	100 million kW
Coal consumption	4.2 billion tce
Maximum share of coal in total primary energy consumption	62%
Minimum share of natural gas in total primary energy consumption	10%

TABLE A.5. China's 2020 Sectoral Targets

Sector	Outcome	2020 Target
Industry	Emissions reduction per unit of industrial added value	Around 50%
	Added value of emerging industries of strategic importance in GDP	Around 15%
	Added value of service industry in GDP	52%
Buildings	Urban green buildings in new buildings	50%
Transport	Public transport share in large and medium sized cities	30%
	CO_2 emissions reduction per road revenue passenger kilometer (RPK)	5%
	CO_2 emissions reduction per road freight tonne kilometer	13%
	CO_2 emissions reduction per unit of railway traffic volume	15%
	CO_2 emissions reduction per unit of waterway traffic volume	13%
	CO_2 emissions reduction per unit of civil aviation traffic volume	11%
Forestry	Forest area increase (ha)	40 million
	Forest reserves increase (m^3)	1.3

Note: All proportional reduction/increase targets are based on a 2010 baseline except for the forest reserve increase target, which is based on a 2005 baseline.

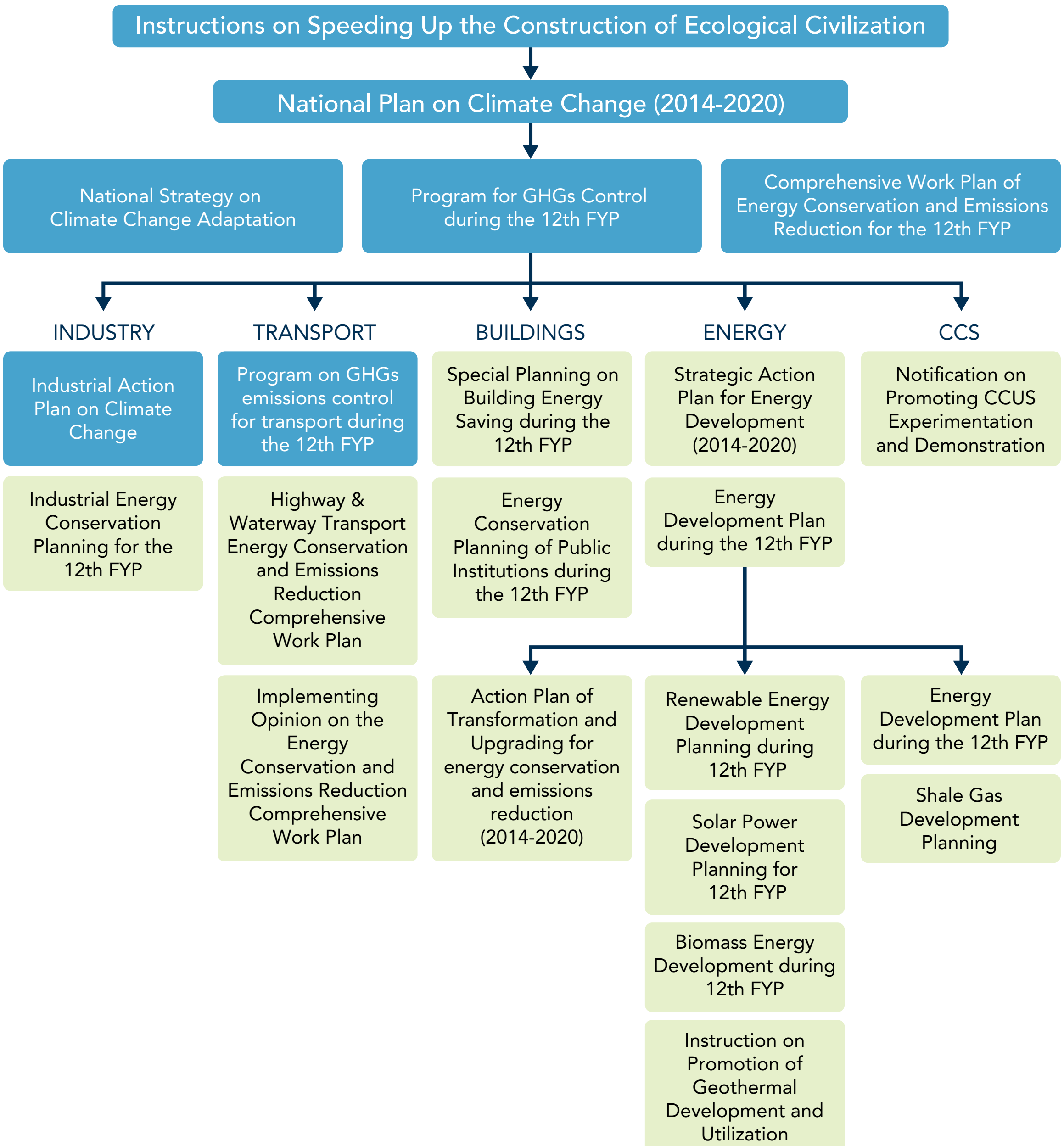
A range of institutions have been established to assess impacts, coordinate responses, and implement policies at different levels. The National Leading Group on Climate Change and Energy Saving was established as a forum for national-level deliberation and coordination, consisting of the Premier, Vice-Premier and leaders from more than 20 ministries. This is supported by the Department of Climate Change, which conducts technical analysis and formulates national climate change strategies, plans and policies. The National Center for Climate Change Strategy and International Cooperation (NCSC) leads national-level research and consulting on climate change. These national institutions are complemented by regional agencies (individual departments or divisions of local Development and Reform Commissions) and local research institutes in the 31 provincial administrative regions.

China has also incorporated climate change into sectoral planning frameworks to ensure appropriate action across the economy. In the context of the 2014 *National Plan on Climate Change,* China has developed a *Work Plan for Greenhouse Gas Emission Control During the Twelfth FYP Period*. This was then incorporated into sectoral development plans, climate change plans and/or energy conservation and efficiency plans in the industry, transport, construction and energy sectors, and into a plan for promoting CCUS experimentation and demonstration, as shown in Figure A.1. These plans include sector-specific measures to accomplish national-level targets from the *National Plan*.

A range of legislative, executive, economic and market-based tools have been put in place. Some of the most important of these include:

- *Legislation and regulations*. More than 30 national laws and 90 administrative regulations relating to low-carbon development have been passed, including energy conservation and renewable energy laws. Various local governments have also introduced subnational climate change regulations in line with national legislation;
- *Executive orders*. This is the most common climate change policy tool in China. One of the key focal areas of executive orders has been to bring about mandatory energy savings and emissions reductions across government, enterprises and society. These orders include

FIGURE A.1. Climate Change Has Been Incorporated into China's National and Sectoral Planning Frameworks



Note: Blue boxes indicate special planning to address climate change.

compulsory standards and/or required actions relating to industrial processes, transport, buildings and government procurement;

- *Economic incentives.* These include pricing systems and fiscal support. Pricing systems include differentiated power pricing in high-energy consuming industries and punitive pricing on products exceeding energy-consumption standards. Fiscal support includes investment subsidies, preferential loans and funding for areas such as renewable energy development;
- *Market mechanisms.* Emission trading schemes currently operate in seven pilot regions, including Beijing and Shanghai. They were launched in 2013 and 2014, with total trading

volumes of 15 million tonnes of CO_2 by the end of 2014. The government is also formulating an overall plan to implement a carbon-trading system which is expected to launch in 2017.

- *Low-carbon development pilot programs.* These have been deployed in six provinces and 36 cities, covering 57% of national GDP and 42% of national population (in 2010), and covering a range of geographies, levels of economic development, and industrialization. The pilots include area-specific development plans for establishing low-carbon industrial, construction and transportation systems, as well as the establishment of systems for GHG emission controls.

China is also expanding its international cooperation on energy and climate issues to support international progress in addressing climate change. This includes support for the international transfer of low-carbon manufacturing and production and the strengthening of international energy cooperation. China is also promoting international cooperation on science and technology, including on research and development, as well as manufacturing techniques and the development of standards. Finally, China is working to strengthen relationships with international organizations to increase capacity building and training.

Annex B: Social, Economic and Environmental Trends in China

Reviewing the trends

Trends in socioeconomic development, including population and urbanisation and energy service demands, will all influence China's emissions trajectory.

Review of Trends in Population and Urbanization

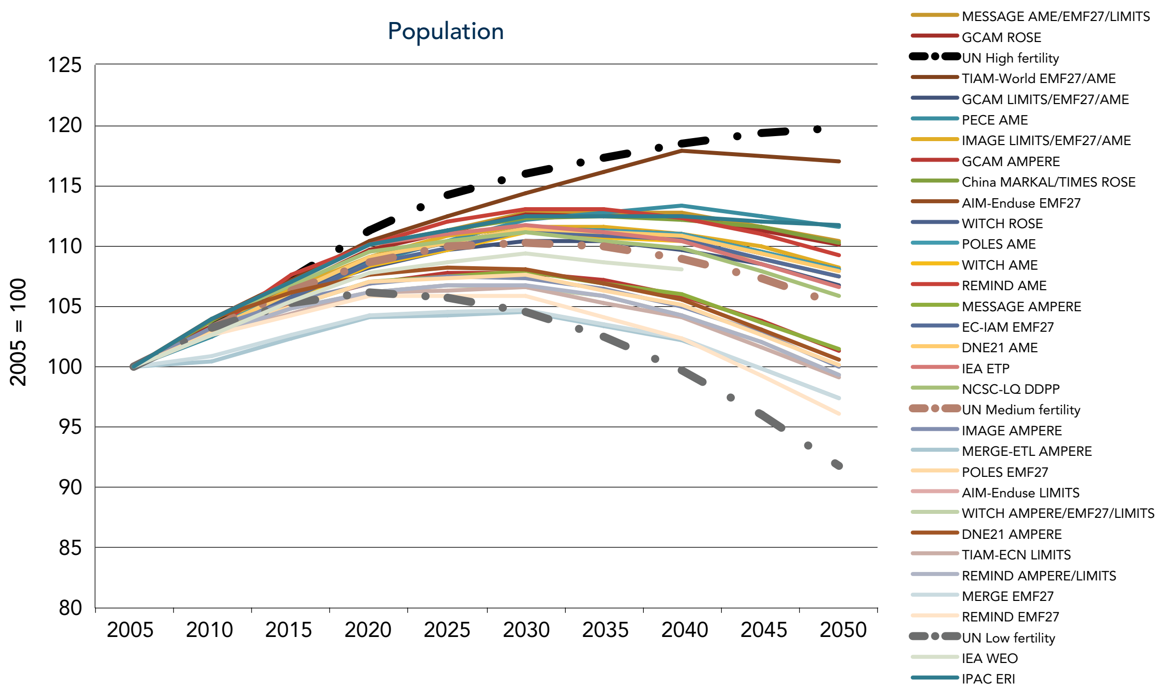
Population has significant implications for energy consumption. Figure B.1 and Table B.1 compare the population assumptions of a range of studies. As can be seen, there is broad consensus on China's population trajectory with some minor differences. Across all scenarios, it is existing government policy that will continue and population growth will continue to increase gradually. The expected changes in population growth between 2005 and 2030 is small, ranging from 5–15%. This reflects a modest change over two decades largely due to the effectiveness of China's population policies. Projections suggest that China's population will peak at approximately 1,450 million people by around 2030.

As noted previously, China is undergoing rapid urbanisation. This urbanization requires extensive material input and can consequently influence emissions levels. Based on historical experience internationally, the urbanisation process has three stages. First, there is the slow development stage which persists until an urbanisation level of approximately 30%. This is followed by the accelerated development stage, and then the modern development stage. The urbanization rate of developed countries is generally more than 70%. Some are higher, such as the US and the UK which are 81% and 90% respectively. Presently, China is in the accelerated development stage of urbanization. Table B.1 sets out the assumptions on future urbanization across different modelling exercises. The models suggest that China's urbanization level will reach 56–63% by 2020, 64–70% by 2030, and 76–79% by 2050. Each percentage point increase in the urbanization rate suggests a shift of about 15 million people.

TABLE B.1. Urbanization Ratio Assumptions from Different Scenarios

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
China MARKAL	43%	49%	52%	56%	60%	64%	68%	71%	75%	78%
PECE	43%	50%	56%	62%	65%	68%	71%	73%	75%	76%
IEA	43%	49%	56%	61%	65%	69%	71%	74%		
IPAC	43%	49%	56%	63%	67%	70%	72%	74%	77%	79%
Medium	43%	49%	56%	62%	65%	69%	71%	74%	75%	78%

FIGURE B.1. Trends in Population Among Different Scenarios



Note: Population changes are indexed to 2005. The 2005 population was 1,300–1,450 million, and an estimated 1,308 million from the NBS.

Trends in Economic Growth

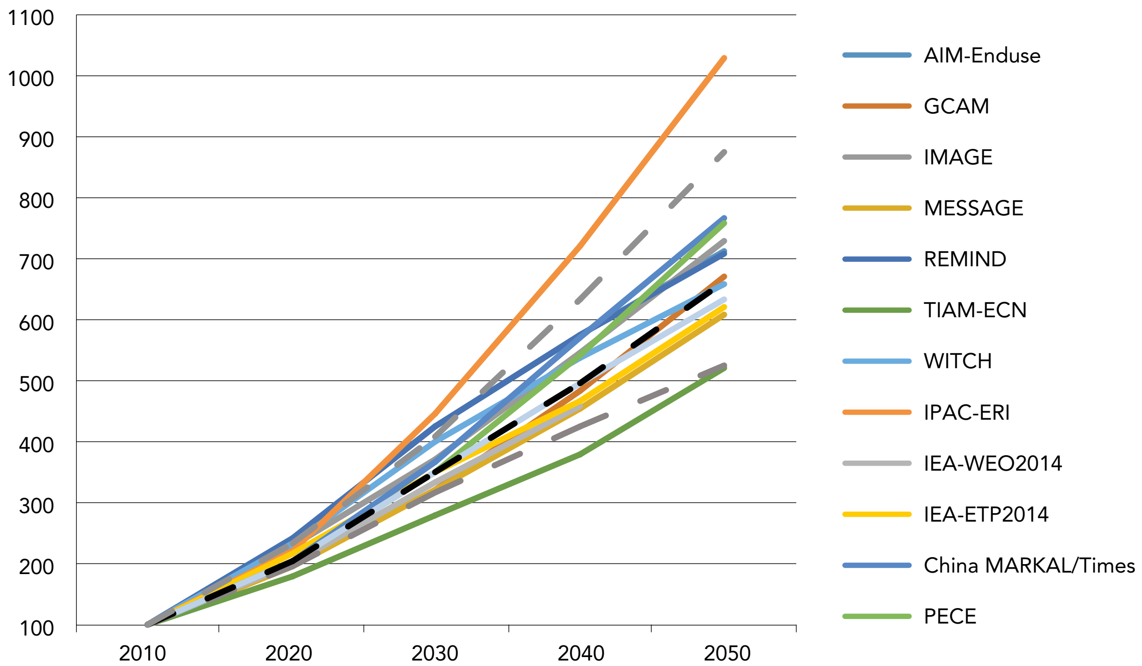
Thus China's economic structure, as well as the rate of economic growth, is one of the key variables determining its future emissions pathways. Industry has been the major driver of emissions growth over the period 2000–14. During the period of almost 40 years since reform and opening up, China's GDP increased by around 9.4% on an average annual basis, and a rapid growth rate was maintained.

Structural changes and growth in the Chinese economy will significantly influence energy demand and emissions. Table B.2 and Figure B.2 contrast the assumptions on the GDP growth rate across various studies. The assumptions in most studies are: 6.9–8.8% for 2010–20; 4.9–5.8% for 2020–30; 3.1–4.5% for 2030–40; and 2.1–3.3% for 2040–50. It is generally assumed that the relatively high rate of growth will continue and gradually drop due to restructuring of the economy towards the new normal, as well as demographic changes. The total GDP in 2030 will be comparable with the US and EU. This would constitute tripling–quadrupling of 2010 GDP. GDP per capita will still be only one-third to one-quarter of that of the US and EU.

TABLE B.2. GDP Growth Rate Assumptions Among Different Scenarios

	2010–20	2020–30	2030–40	2040–50
AIM-Enduse	9.2%	5.8%	3.1%	2.1%
GCAM	6.9%	5.2%	4.1%	3.3%
IMAGE	8.8%	4.8%	3.9%	3.0%
MESSAGE	6.9%	5.1%	3.5%	2.9%
REMIND	9.2%	5.8%	3.1%	2.1%
TIAM-ECN	6.1%	4.4%	3.2%	3.2%
WITCH	8.8%	5.6%	3.0%	2.1%
IPAC-ERI	8.4%	7.1%	5.0%	3.6%
IEA-WEO2014	7.2%	5.3%	3.2%	
IEA-ETP2014	8.1%	4.9%	2.9%	2.9%
China MARKAL	7.4%	6.0%	4.5%	3.0%
PECE	7.4%	5.5%	4.5%	3.4%
NCSC (DDPP)	7.5%	5.5%	3.5%	2.5%
Among Which:				
20th percentile	6.9%	4.9%	3.1%	2.1%
Median	7.5%	5.5%	3.5%	3.0%
80th percentile	8.8%	5.8%	4.5%	3.3%

FIGURE B.2. Trends in GDP Growth Among Different Scenarios



Note: GDP per capita changes are indexed to 2010. 2010 GDP per capita levels ranged from US$2,300 to $3,400 per capita (2005 price). The official NBS estimate was $2,900.

Trends in Energy Service Demand

The future demand for energy services will be a key driver in overall energy demand and CO_2 emissions. The demand for energy services includes demand for high-energy consuming products, transportation, and building space and construction. Tables B.3, B.4 and B.5 compare the assumptions on the future energy service demand across the various scenarios reviewed. Several conclusions can be drawn from the tables. First, there is a wide range of projected drivers for energy service demand in the residential and transport sectors in China to 2050. Few models explicitly assess this parameter and those that do use different base-year data. Second, activity levels for the analysed sectors are projected to grow by around a factor of 5 on average for passenger/freight kilometres, and 1.6 on average for residential and commercial floor space. This is consistent with a transition from industrial to transport and residential energy demand. Controlling these emissions may be a major challenge for China in the future, and should be subject to more intensive scenario assessment.

TABLE B.3. Comparison of Energy Service Demand for Residential and Commercial Floor Space (billion m²/year)

Model	Scenario	2005	2010	2015	2020	2025	2030	2040	2050
China MARKA	ROSE	38.6	46.7	56.6	62.9	68.3	73.7	84.0	93.2
GCAM	LIMITS-StrPol	53.1	56.2	59.6	62.9	65.9	68.7	73.6	77.0
POLES	AMPERE	15.4	18.4	23.2	28.0	32.3	36.7	41.7	44.5
PECE	AME	38.6	46.7	52.2	58.8	65.0	70.0	74.1	76.3
IEA	WEO	34.2	40.4	45.9	50.6	53.8	57.0	60.2	
Medium		**38.6**	**46.7**	**52.2**	**58.8**	**65.0**	**68.7**	**73.6**	**76.7**

TABLE B.4. Comparison of Energy Service Demand for Freight Transportation (billion tonne-km/year)

Model	Scenario	2005	2010	2020	2030	2040	2050
AIM-Enduse	EMF27-Base-FullTech	2,338.7	2,878.5	4,117.2	5,644.3	7,530.9	9,842.8
POLES	EMF27-Base-FullTech	2,941.9	4,265.1	8,280.5	12,460.3	15,458.9	1,7885.7
GCAM	LIMITS-Base	6,802.5	8,232.5	11,021.2	13,664.9	16,235.8	18,759.6
GCAM	EMF27-Base-FullTech	6,802.5	8,232.5	11,021.5	13,665.7	16,239.0	18,766.4
GCAM	ROSE BAU DEF	6,802.5	8,189.8	11,904.9	15,371.6	17,741.8	19,567.3
GCAM	AMPERE2-Base-FullTech-OPT	6,802.5	8,322.4	12,331.7	15,721.6	17,873.2	19,639.0
POLES	AMPERE2-Base-FullTech-OPT	2,819.4	4,936.4	13,837.1	20,903.8	22,438.8	23,399.7
PECE	AME	9,394.0	14,454.0	27,686.0	42,337.0	61,398.0	75,660.0
China MARKAL	ROSE		13,964.1	23,003.1	38,347.6	56,253.3	75,691.7

TABLE B.5. Comparison of Energy Service Demand for Passenger Transportation (billion passenger-km/year)

Model	Scenario	2005	2010	2020	2030	2040	2050
GCAM	AMPERE2-Base-FullTech-OPT	1,504.0	2,148.3	4,069.4	5,862.6	6,994.0	7,787.5
GCAM	LIMITS-Base	1,504.0	2,128.7	3,521.5	4,977.2	6,434.7	7,797.4
GCAM	EMF27-Base-FullTech	1,504.0	2,128.7	3,521.5	4,977.4	6,435.4	7,798.7
GCAM	ROSE BAU DEF	1,504.0	2,131.2	4,006.1	5,836.7	7,111.5	8,064.1
DNE21	AMPERE2-Base-FullTech-OPT	2,733.7	3,518.3	5,034.0	6,911.7	8,525.4	10,031.9
AIM-Enduse	EMF27-Base-FullTech	1,872.2	2,507.6	4,013.1	6,071.8	9,024.5	13,231.3
POLES	AMPERE2-Base-FullTech-OPT	2,941.9	4,265.1	8,280.5	12,460.3	15,458.9	17,885.7
POLES	EMF27-Base-FullTech	2,819.4	4,936.4	13,684.0	20,617.0	22,198.8	23,096.5
PECE	AME	3,446.0	5,163.0	10,056.0	16,085.0	20,849.0	26,019.0
China MARKAL	ROSE		3,545.6	10,314.4	16,229.6	21,601.9	28,424.6

Assumptions on Key Drivers in NDC Scenario

The NDC scenario used in this report is based on a number of economic and demographic assumptions that influence the overall trend in emissions. Table B.6 summarises these different assumptions. Population is predicted to increase before a peak at around 1,467 million in 2030. This will then gradually fall to 1,449 million in 2050. The urbanization rate will increase from 48% in 2010 to about 68% in 2030, and then to 78% in 2050, with more than 480 million people moving into cities. The GDP growth rate will slow with the economic shift to the new normal. GDP per capita is anticipated to increase more than threefold between 2010 and 2030, and more than sixfold between 2010 and 2050. The economy will be restructured with the shift to the new normal. The share of primary industry will continue to decrease, and the share of secondary industry will reach a peak (about 50%) between 2010 and 2015 and then begin to decrease. The share of tertiary industry will keep increasing until reaching around 58% by 2050. Demand for energy services in the building and transport sector will grow significantly until 2050, in line with economic growth. The demand for residential and commercial floor space in 2030 and 2050 will be around 1.5–1.6x the 2010 level, respectively. Demand for both freight and passenger transportation will increase fivefold between 2010 and 2050.

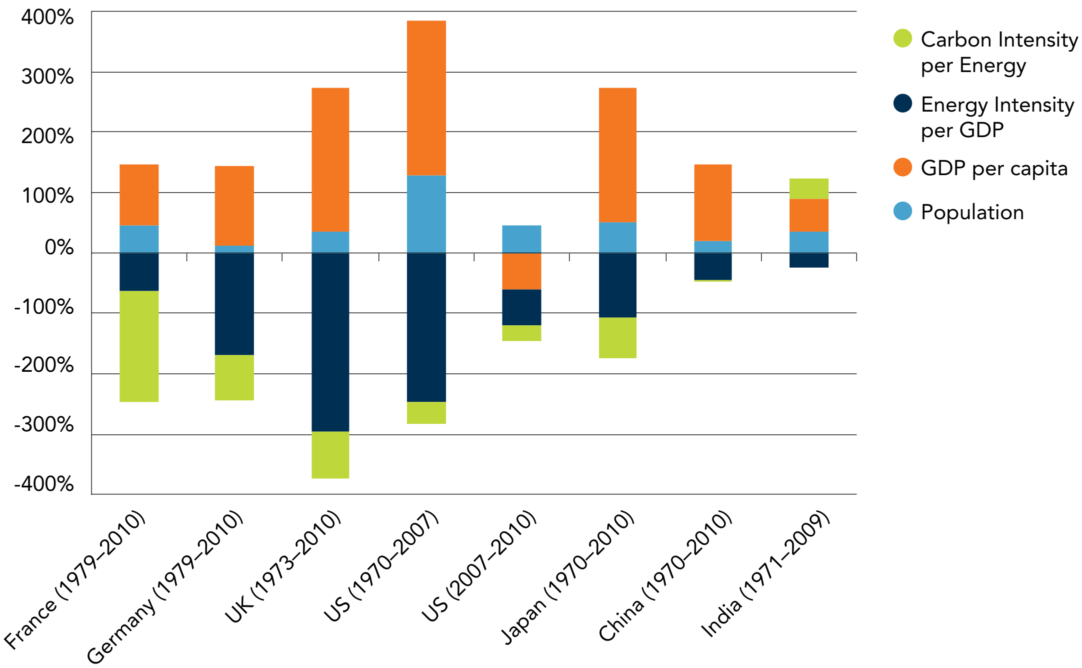
TABLE B.6. Key Assumptions and Projections in the NDC Analytical Scenario

	2005	2010	2015	2020	2030	2040	2050
Population (million)	1,308	1,341	1,375	1,408	1,467	1,462	1,449
Urbanization Rate	43%	48%	55%	60%	68%	74%	78%
GDP per Capita, US$ (2010 prices)	2,708	4,503	6,429	8,639	14,026	21,245	29,938
GDP Growth Rate	—	11.3%	7.9%	6.6%	5.4%	4.2%	3.4%
Residential and Commercial Floor Space (billion m^2)	38.6	46.7	52.2	58.8	70.0	74.1	76.3
Residential Floor Space per Capita (m^2)	25.2	29.0	31.1	33.8	37.7	39.3	40.3
Freight Transportation (billion tonne-km)	9,394	14,454	21,070	27,686	42,337	61,398	75,660
Passenger Transportation (billion passenger-km)	3,446	5,163	7,610	10,056	16,085	20,849	26,019

Annex C: International Emissions Drivers Comparison

This section reviews the historical emissions trajectories of developed countries using a Kaya decomposition. An overview of emissions from major economies between 1979–2010 using a Kaya decomposition is provided below in Figure C.1. It will identify key features and policies from the experience of developed countries in order to develop lessons for China and other developing countries in implementing their NDCs.

FIGURE C.1. Kaya Decomposition of Major Economies



Data source: Population, GDP and energy data are from the World Bank database 2012; Chinese energy data was gathered from the Energy Statistics Yearbook; CO_2 emissions data was compiled from CDIAC

Globally, population growth and per capita GDP growth have been the primary drivers of GHG emissions during 1971–2010. Over the same period, energy consumption per unit of GDP declined. However, carbon intensity per unit of energy consumption has shifted from being an emissions reducing driver between 1970 and 2000 to being an emissions increasing driver between 2000 and 2010. These trends demonstrate the role that energy efficiency can play as a low-cost mitigation option. This is supported by work from the United Nations Environment Programme (UNEP) which estimates the mitigation potential of energy efficiency to be 2.0 $GtCO_2$ equivalent in 2020 (UNEP 2013). Beneath these wider international trends, the drivers of emissions reduction have varied between countries.

The EU

Only major EU countries have successfully reduced their emissions significantly over the longer term after peaking. This was driven by a relatively low population growth rate (0.3 % per year), lower per capita GDP growth rate (approximately 2% per annum), and a substantial decline in energy intensity and carbon intensity. The situation differs from country to country. For France, decarbonization of the energy structure, particularly through the introduction of nuclear energy, was the main factor in CO_2 emissions reduction. While the energy intensity per unit of GDP fell by 21% between 1979 and 2010, carbon intensity per unit of energy declined by around 50% in the same period. For Germany and the UK, energy intensity decline was the key factor, achieved mainly through industrial structure adjustment and energy efficiency improvement. In the UK, energy intensity fell by 58% and carbon intensity by 20% between 1973 and 2010. In Germany, the energy intensity per unit of GDP fell by 47% between 1979 and 2010, while the carbon intensity of energy use fell by 24% over the same period. It appears that future emissions reduction in Germany may be driven more by reductions in carbon intensity due to substantial changes in energy policy.

Two months after the Fukushima meltdown in Japan in 2011, Germany announced that it would close down all nuclear power plants by 2022 (Breidthardt, 2011). After half-a-century's development, nuclear power had become a key pillar of its energy mix, accounting for 22.4% of the total electricity generating capacity in 2010 (IEA, 2016). Shortly afterwards, the German government presented the systematic 'Energiewende' strategy. The Energiewende is considered to be the largest package of reform measures taken by Germany since reunification. The strategy establishes both the 2022 deadline for the phase out of nuclear power as well as several long-term mandatory targets. These include a target for renewable energy to account for 80% of the German energy mix by 2050, as well as an emissions reductions targets of 40% by 2020 compared to 1990 (Morris and Pehnt, 2016).

The advanced low-carbon development of the EU is a direct result of its focus on top-level strategic design. In 2008, the EU proposed a package of energy and climate plans, including:

- Amendments to the EU Emissions Trading Scheme (EU-ETS);
- Changes to the EU Member States' effort-sharing decision;
- The development of a legal framework for CCUS;
- The creation of a Renewable Energy Directive;
- The establishment of vehicle CO_2 emission regulations; and
- A Fuel Quality Directive.

These were followed by the publication of a low-carbon technology road map by the European Commission in 2009. In 2014 the Commission then published a White Paper on a 2030 climate and energy policy framework and proposed new emissions reduction targets of 40% compared with 1990.

The EU Emissions Trading Scheme (EU-ETS) is the centrepiece of the EU's climate and energy policy. The EU-ETS is the largest cross-border, multi-sector GHG emissions trading system in the world. It covers the 28 EU Member States and some enterprises from Norway, Iceland and

Liechtenstein. The emissions covered by the EU-ETS account for 45% of the EU's total CO_2 emissions. The design and rules of the EU-ETS have provided an insight for the development of carbon markets in other countries, including pilot schemes in China.

Japan

GDP per capita growth was the major driver of Japan's CO_2 emissions between 1970 and 2010, while improvements in energy intensity were an offsetting factor. Japan has few domestic reserves of fossil fuels, and is highly dependent on energy imports. This means that its emissions profile is strongly affected by international energy shocks. After the first oil shock in the 1970s, Japan's energy policy priorities shifted to the development of nuclear, liquefied natural gas (LNG), and imported coal. This was done as a direct response in order to limit dependency on the volatile oil market. Nuclear power had been the most important energy source until the Fukushima Daiichi Nuclear Power Plant accident in March 2011. The subsequent suspension of nuclear plants and resurgence of fossil fuels, especially LNG, led to a dramatic increase in its carbon intensity of energy use between 2011 and 2012 (DDPP).

Japan has developed numerous policies to reduce its GHG emissions. In 2012, a carbon tax was set at US$2.12 per kiloliter of oil. All proceeds from the tax were used for renewable energy and energy efficiency initiatives. In 2011, an act[17] was passed that requires utilities to purchase power generated through renewable energy using a high, fixed-price contract. There are also tax incentives and preferences granted to high-efficiency buildings and those that deploy rooftop solar PV. Since 1998, Japan's Top Runner program, which sets mandatory standards based on the most efficient products on the market, has reduced energy consumption by 8% in the residential sector and 5% in road transport. Japan has also implemented mandatory building energy efficiency design standards. In 2010, it published its Low Carbon City Development Guidance to support local authorities in promoting and planning for low-carbon city development. This included a description of methods and measures to pursue compact urban areas where people can live closer to their workplaces, reducing travel distances and alleviating transportation demand.

The US

The emissions profile of the US is more complex than its OECD counterparts. Its per capita emissions peaked in 1973, but due to rapid population growth its total emissions didn't peak until 2007. Emissions reductions in 2008 and 2009 after the 2007 peak were namely due to the financial crisis rather than policy efforts. Emissions rebounded in 2010 before reducing through to 2014 due to the development of renewable energy and shale gas exploration. These reductions have occurred alongside consistent economic growth.

The development of shale gas, and the corresponding policy adjustment, have changed the US from being the largest importer of natural gas to an LNG exporter. This policy adjustment will not only benefit natural gas importing countries, but will also improve domestic gas production sustainability. US LNG export volumes in 2020 and 2030 will reach 42 and 73 million tonnes respectively (US EIA, 2016). This growth trend is expected to continue until 2040.

17 The Act on Special Measures concerning the Procurement of Renewable Electric Energy by Operators of Electric Utilities.

US climate policy has been marked by executive policy actions and state-based initiatives in the absence of federal level policies. Many US states, such as California, New Jersey and Florida, have developed long-term GHG emissions reduction and renewable energy targets. In 2009, the Obama administration proposed to increase the share of renewable energy in the total energy mix to 10% by 2012 and 25% by 2050. In 2009, the Clean Energy and Security Act proposed a GHG emissions reduction target of 17% in 2020, compared with the 2005 level, and an 83% reduction against the same level in 2050. The Obama administration also issued a Presidential Climate Action Plan. In March 2015, the US submitted its NDC to the UNFCCC Secretariat, committing to cut emissions by 26–28% below its 2005 levels by 2025, with the proposed Clean Power Plan (CPP) among its key policy measures.

The US was among the first countries to promote energy efficiency standards and labelling through national legislation. In 2009, it issued a new fuel economy standard that required all the cars manufactured and sold in the US to meet certain standards by 2011. These standards have been specified for each manufacturing company and for different sizes of vehicle. This mix of executive and state actions across energy efficiency, energy policies and transport standards provides a policy package that developing countries, including China, can draw lessons from.

Annex D: The PECE Model

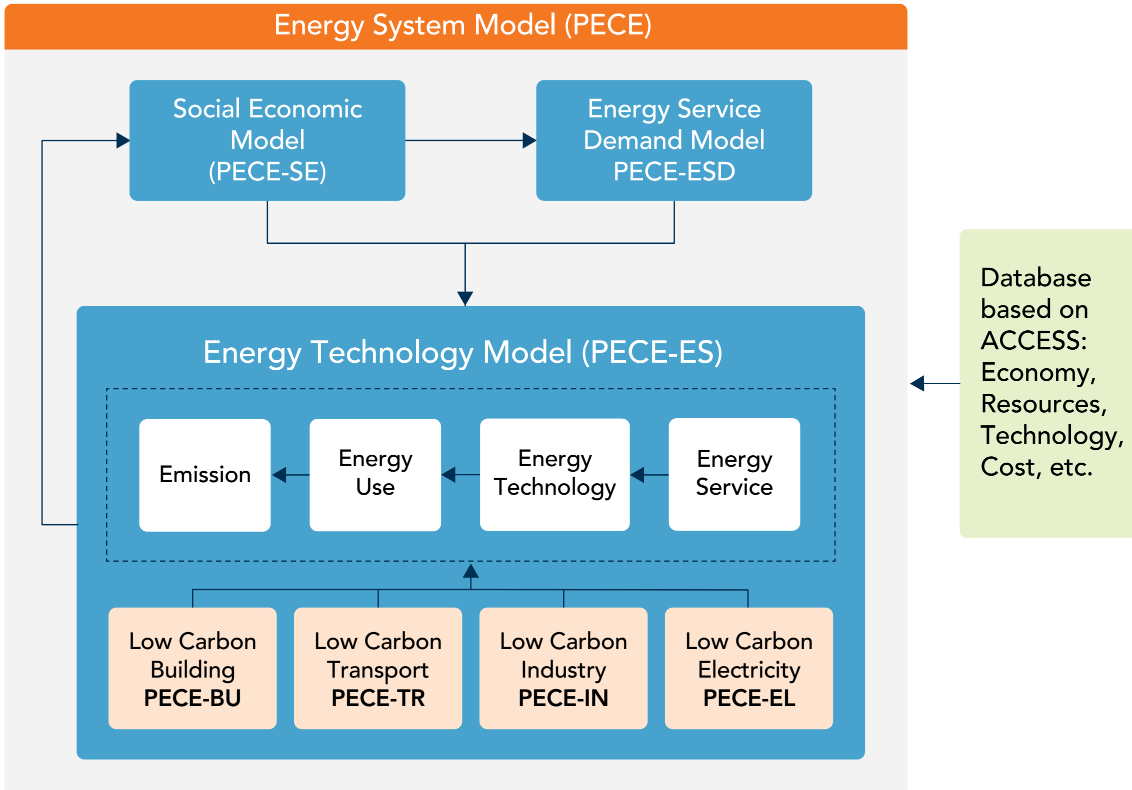
The PECE Model[18] and Scenarios

This report used the PECE model which was co-developed by NCSC and the Renmin University of China (RUC). The PECE Model was developed using the General Algebraic Modelling System (GAMS), which is a high-level modelling system for mathematical programming and optimization. The PECE model was designed for comprehensive, dynamic, nonlinear optimization problems. In most cases, the model uses the CONOPT solver: a GRG-based algorithm specifically designed for large-scale nonlinear optimization problems.

The PECE model consists of three coupled sub-models: a bottom-up technology sub-model of energy supply and consumption of an individual country (PECE-ES); a social economic sub-model based on production function approach (PECE-SE); and a quantitative energy service demand sub-model (PECE-ESD). Among these sub-models the PECE-ES is the core. The PECE-ES model is a bottom-up nonlinear technology optimization model in which least cost technology choices are made under a series of restrictions, e.g., the demand for energy services, the restriction on energy supply, etc. The costs calculated in the model include annualized fixed cost of recruited devices during that year, variable operation cost (operation and maintenance cost of devices, and fuel cost), the cost of installing removal devices such as CCUS and cost of emissions taxes. The model is based on the partial equilibrium framework and is used as a tool to estimate both future energy demand and emissions. It simulates the flows of energy and materials in an economy, from the source or supply of primary energy and materials, through conversion into secondary energy and materials, and through to the delivery of various forms of energy to the end-use services. In the model, these flows of energy and materials are characterized through detailed representation of technologies providing an end-use scenario driven analysis. The model also considers the existing device quantities in the starting year of the scenario horizon in order to calculate device life span. The structure of the PECE Model is shown in Figure D.1.The PECE-ESD model is a sub-model serving to estimate the demand of energy service, such as the production of energy intensive products and demand for passenger and freight transportation as well as for building (square meters). The main inputs of the model are population, GDP and value added of industries, etc. S-shaped logistic curve is adopted for projection with consideration of level of saturability.

18 Fu Sha, Study on China's Low Carbon Development Technology Strategy and Policy Options based on an Energy System Model, Ph.D thesis of Renmin University of China, 2012

FIGURE D.1. Structure of the PECE Model



The NDC scenario in this report uses the three main goals in China's NDC as constraint conditions. These are by 2030 to 1) peak carbon emission; 2) reduce carbon intensity by 60%–65% compared to the 2005 levels; and 3) increase forest stock volume by 4.5 billion. Based on the constraint conditions and energy demand, the PECE model computed and selected carbon reduction plans that either optimized the reduction cost or had the largest carbon reduction potential. The model uses 2005 as the base year and analyses the period from 2005 to 2050 with special emphasis on three critical years of 2020, 2030 and 2050. The NDC scenario has considered the impact of adjusted energy data for China while a lot of scenario compared in this report has not. The timing and scale of adoption of certain potential initiatives such as CCS and curtailment of coal has been analysed.

Strategy Analysis on Climate Change in China Model (SACC)

The Strategy Analysis on Climate Change in China model (SACC) developed by NCSC is a bottom-up model, including an accounting model for terminal industries, and an energy technology optimization model for energy production and transformation industries. The SACC model uses 2010 as a base year and is designed to study short-term (before 2020), medium-term (2020–2030) and long-term (2030–2050) energy demands of end-use sectors by taking into account the different energy activities, structures, efficiencies and other key factors under baseline, positive and enhanced scenarios. The variation of primary energy consumption demands and carbon emissions are studied and compared through the model.

The BAU scenario in this report is developed by SACC which takes consideration of the current policies and measures up until the 12th FYP. It uses intensity control measures (including carbon emission per unit of GDP and energy consumption per unit of GDP targets) as the main means to create low-carbon development.

Scenario Selection Criteria

In order to evaluate the ambition of China's NDC targets in relation to a 2°C scenario, this report selected 30+ scenarios from project specific databases of the nine model intercomparison projects that are included in the IPCC AR5 database. A list of these different scenarios is provided below in Table D.1. These 30+ scenarios are results from widely used models such as GCAM, IMAGE, MERGE, MESSAGE, POLES, REMIND, TIAM-ECN, and WITCH. All of the selected scenarios include detailed information on China, impose no limitation on technology availability, and are likely to achieve the 2° target. Moreover, results of the selected scenarios are mostly consistent with China's historical performances. 30+ scenarios were removed from the original selection as their 2010 and 2015 emission results had significant discrepancy from China's historical emissions. All selected scenarios have not been adjusted after China's energy data revision.

TABLE D.1. List of Selected 2°C Scenarios[19]

Model	Scenario	Model	Scenario
GCAM	AMPERE2-450	POLES	AMPERE2-450
GCAM	LIMITS-StrPol-450	POLES	EMF27-450
GCAM	LIMITS-StrPol-500	REMIND	AMPERE2-450
GCAM	LIMITS-RefPol2030-500	REMIND	LIMITS-500
GCAM	LIMITS-RefPol-450	REMIND	LIMITS-StrPol-450
GCAM	LIMITS-RefPol-500	REMIND	LIMITS-StrPol-500
IMAGE	AMPERE2-450	REMIND	LIMITS-RefPol2030-500
IMAGE	LIMITS-450	REMIND	LIMITS-RefPol-450
IMAGE	LIMITS-500	TIAM-ECN	LIMITS-StrPol-500
IMAGE	LIMITS-StrPol-450	WITCH	AMPERE2-450
IMAGE	LIMITS-StrPol-500	WITCH	EMF27-450
IMAGE	LIMITS-RefPol2030-500	WITCH	LIMITS-500
IMAGE	LIMITS-RefPol-450	WITCH	LIMITS-StrPol-450
IMAGE	LIMITS-RefPol-500	WITCH	LIMITS-StrPol-500
MERGE	EMF27-450	WITCH	LIMITS-RefPol2030-500
MESSAGE	AMPERE2-450	WITCH	LIMITS-RefPol-450

19 LIMITS Scenario Database (2014). available: http://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/LIMITs_Scenario_Database.html
AMPERE Scenario Database (2014), available: http://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/AMPERE_Scenario_database.html
EMF27 database (2014), available: http://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/EMF27DB.html

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