CN 2015 Report

pathways to deep decarbonization *in China*

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SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

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Deep Decarbonization Pathways Project

The Deep Decarbonization Pathways Project (DDPP), an initiative of the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI), aims to demonstrate how countries can transform their energy systems by 2050 in order to achieve a low-carbon economy and significantly reduce the global risk of catastrophic climate change. Built upon a rigorous accounting of national circumstances, the DDPP defines transparent pathways supporting the decarbonization of energy systems while respecting the specifics of national political economy and the fulfillment of domestic development priorities. The project currently comprises 16 Country Research Teams, composed of leading research institutions from countries representing about 70% of global GHG emissions and at very different stages of development. These 16 countries are: Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea, the United Kingdom, and the United States.

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The Institute for Sustainable Development and International Relations (IDDRI) is a non-profit policy research institute based in Paris. Its objective is to determine and share the keys for analyzing and understanding strategic issues linked to sustainable development from a global perspective. IDDRI helps stakeholders in deliberating on global governance of the major issues of common interest: action to attenuate climate change, to protect biodiversity, to enhance food security and to manage urbanization, and also takes part in efforts to reframe development pathways.

SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
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The Sustainable Development Solutions Network (SDSN) was commissioned by UN Secretary-General Ban Ki-moon to mobilize scientific and technical expertise from academia, civil society, and the private sector to support of practical problem solving for sustainable development at local, national, and global scales. The SDSN operates national and regional networks of knowledge institutions, solution-focused thematic groups, and is building SDSNedu, an online university for sustainable development.

NCSC

The National Center for Climate Change Strategy and International Cooperation (NCSC) is an institutional organization directly subordinate to the National Development and Reform Commission (NDRC) and the only national-level research center that works on climate change strategy and international cooperation. NCSC conducts systematic studies on climate change strategic planning, policies and regulations, international negotiation and cooperation, statistics and assessment, carbon market management and information consulting. There are more than 70 researchers working in NCSC, who have accumulated wide international views and rich experiences with a long-term involvement into many international and national key studies on environmental economy, energy and climate change.

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Institute of Energy, Environment and Economy (3E) was established in 1980 in Tsinghua University. 3E is a pioneer and a top think tank in terms of research on energy systems analysis and climate change in China. 3E has more than 30 full time researchers working on energy and climate change model, energy strategy and planning, low carbon development, international climate regime, new and renewable energy, energy efficiency and energy conservation.

This report was jointly prepared by National Center for Climate Strategy and International Cooperation (NCSC) and Institute of Energy, Environment and Economy, Tsinghua University

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Executive summary

This China country report by the country team in the Deep decarbonization pathway project (DDPP) summarize the key findings of the technical pathways developed by the Chinese team, with a view to achieve deep reduction in the longer term for China. The forthcoming Paris climate conference will lay out a foundation for the future international climate regime building upon the intended nationally determined contributions (INDC) submitted by various Parties. As the largest developing countries, China is also in the frontline to combat with climate change. This country report start by summarizing the national circumstance of China which set an important narrative to understand China's mitigation policies. Decision makers in China are facing multiple challenges including further develop its economy to enter into high income stage, secure its energy system to power ongoing urbanization and industrialization, improve air quality to enhance public health and local environment and control carbon emission to manage the long-term climate risk. To cope with climate change is no longer regarded as a cost, but rather an opportunity to help China deliver those social economic objective in terms of better growth, better environment and better energy infrastructure. From that perspective, a low carbon pathway is largely consistent with China's domestic interest. A deep decarbonization pathway therefor is developed in this report to illustrate the possible trajectory that lead China to a low carbon future. A more detailed analysis is also conducted at sector level to analyze the possible technical solution for the transition towards a deep decarbonization pathway. We also consider three key factors which may have important impact on the deep decarbonization pathway of China, including the replacement for coal with electricity in industry sector, the penetration rate of electric cars in transportation sector and the potential of carbon capture, utilization and storage (CCUS). The DDPP is illustrative for China and associated challenges are also identified which includes the uncertain GDP growth in the future, the adjustment of economic structure and change of development mode, the development of non-fossil fuel in energy sector and behavior change in the urbanization process. All those factors suggest a strong policy response is needed for China to such transition towards a deep decarbonization pathways. Finally we provide several policy recommendation which we believe is necessary for China to decaronize its economy and energy system. Firstly, China need to gradually promote the transition from carbon intensity control towards total emission control. Secondly, this policy intervention will create space to internalize the cost of carbon and China should rely more on market based measure to guide the action of various stakeholders. The market and internalization of carbon cost will increase the competitiveness of low carbon technology and accelerate the transition to a low carbon energy system. Thirdly, the reform is required for Chinese statistical system to improve accountability and progress track. Last but not least, the consumer behavior should be carefully consider during the policy design.

1 Country Profile

1.1 The national context for deep decarbonization and sustainable development

As a result of China's rapid economic growth, its carbon emissions per capita have nearly quadrupled since 1990. In 2007, China surpassed the US as the world's largest CO_2 emitter,[1] and as of 2013 the country accounts for about 27% of world GHG emissions. However, according to most indicators, China remains a developing country: Its income per capita remains well below that of developed countries (even in eastern China, where the level of development is much higher than the national average).

China's future development needs are expected to drive up both its energy consumption and its CO_2 emissions. Considering China's increasingly large share of global emissions, the country's active engagement in addressing climate change is a prerequisite to establish emissions guidelines compatible with the predicted 2-degree temperature increase by the end of the century. However, China's rapidly increasing energy consumption, which is dominated by coal usage, has created additional environmental problems, including local air pollution and depletion of water resources, as well as surging CO_2 emissions. In light of the urgent need to tackle climate change and other serious local environmental issues, China needs to transit to a low-carbon development pathway while meeting its domestic development needs.

a) Growing China's economy is still at the top of the political agenda.

For a number of pragmatic reasons, the government of China remains focused on economic growth.

First, China still needs to grow its economy in order to alleviate poverty, despite three decades of miraculous development. As of 2008, nearly 13% of the total population – approximately 170 million people – were still living on less than US$2.00 (2005 PPP) a day, the poverty line drawn by the World Bank.

Second, local governments in China, especially those in the western provinces, need to maintain high economy growth in order to generate sufficient revenue to cover the costs of various responsibilities required by upper level governments including (but not limited to) social security, education, medical care, public security, environmental protection, and rural and urban infrastructure. The current taxation system concentrates the majority of tax revenue in the budgets of the central government, but the transfer payments do not ensure distribution of adequate financial resources to where they are needed. It is an open secret that local governments have to generate their own revenue by encouraging business growth and investment as well as infrastructure development.

Third, local government officials are highly motivated to expand the economy rapidly, because their individual promotion is closely linked to the growth rates they achieve. The need to transition to a more sustainable development pattern is consistent with the concept of "the new normal" in China's economy, which refers to a new pattern of economic growth amid the maturing of the Chinese economy. Adapting to "the new normal" is a strategic choice by the government to help the economy maintain steady and healthy development despite a slower growth rate. Under the new normal, China will shift from high-speed growth to moderately high growth. A growth model that

1 In this report, CO_2 emissions (carbon emissions) refers to fossil-fuel CO_2 emissions

relies on blind investment, unscrupulous use of resources, and neglect of environmental protection will gradually be eliminated, and the growth model's focus will shift from quantity and speed to quality and efficiency.

b) Ongoing urbanization and industrialization processes have long-term implications for China's emission trajectories and energy consumption.

Industrial production coupled with economic growth has boosted China's massive urbanization at a rate and on a scale unprecedented in the world. Each year, millions of rural workers move into cities, motivated by the prospect of higher wages. In 2011, China's urban population exceeded its rural population for the first time in history; by 2030, another 330 million people are expected to move into cities. These new urban residents will increase the demand for infrastructure, building materials and consumer goods. Consequently, more energy will be consumed and more carbon will be emitted, but advancement in energy efficiency and non-fossil fuels fails to keep pace with the increase of energy consumption needs. On average in 2012, China's urban residents consumed 1.4 times more direct energy than its rural residents;[2] that gap further increases when the energy embedded in goods is taken into consideration. These urbanization trends have long-term implications for climate policy. Rising urban demand necessitates investments in capacity that may lock in energy-intensive infrastructure and industrial arrangements that will prove difficult to alter in the near future. In parts of western and central China, where the process of economic growth has been particularly pronounced in recent years, this lock-in effect on an energy- and emission-intensive path is already taking place.

c) Balancing energy security and environmental protection is a significant challenge for China's energy system

China's energy system faces many problems, three of which are particularly prominent:

(1) *Barriers to transitioning to new energy sources*. China's total energy demand continues to grow. Although investment in renewable energy and energy conservation has developed rapidly in recent years, total energy demand has increased even faster, leading to increases in the consumption of coal, oil, and other fossil fuels. Specifically, under a coal-dominated natural resource endowment, which makes coal much cheaper than other energies, it's difficult for China to diversify its energy supply.

(2) *Fossil-fuel-related pollution.* Increased usage of fossil fuel energy has caused serious problems for the environment, an issue that has attracted more and more attention. The thick fog and haze that fills the air of Beijing, Tianjin, and Hebei province is caused by both coal combustion and vehicle exhaust emissions and contains dangerous levels of particulate matter (PM 2.5).

(3) *Increasing dependence on foreign energy.* China's growing energy demand has also caused China to rely more and more on foreign sources of energy. By 2020, the share of imported oil is expected to reach 70%, and the share of imported natural gas, 50%, creating problems for China's energy security and trade balance. Conflicts and geopolitical tensions in energy supply countries could cause temporary shortages and rising prices, posing a risk to the stability of China's economy. China could reduce its dependence on foreign energy by producing more coal domestically, but this would cause other problems, especially those related to environment concerns.

2 Data are retrieved from China's energy statistical yearbook 2013

d) Air quality has become the number one cause of social instability in China, and the way China controls its air pollution will have a significant impact on efforts to address global climate change.

China's poor air quality has become the number one cause of social unrest and a threat to political stability. It is also causing millions of premature deaths every year and costing billions dollars in environmental damage. Fine particles — including soot, organics, and sulphates — have a severe effect on human health and are implicated in climate change. They are emitted by combustion and industrial processes and formed via the reactions of gaseous pollutants. If China's proposed air quality standard were achieved everywhere in the country, there would be far-reaching benefits beyond the protection of human health, including a slowdown of greenhouse gas emissions. (Air and mercury pollution in the entire Northern Hemisphere would also fall.)

On February 29th 2012, China's State Council approved its first national environmental standard for limiting the amount of PM2.5 particles[3] in the air to an annual average of 35 micrograms per cubic metre by the end of 2015, consistent with the recommendations of the World Health Organization. In September 2013, the State Council unveiled its long-awaited "Atmospheric Pollution Prevention Action Plan" in response to the severe air pollution that has increasingly damaged China. The goal of the new plan is to improve the air quality of the entire country by 2017, while imposing strict air-pollution-reduction guidelines in three key industrial areas surrounding Beijing, Shanghai, and Guangzhou. The way in which air quality in China is controlled will affect global climate in complicated ways. On one hand, reducing soot emissions by cutting coal use or using cleaner stoves will decrease radiative forcing and thus limit warming, benefiting both the climate and public health. A stricter emissions standard for diesel vehicles, which produce soot, is another win-win solution. On the other hand, reductions in SO2 emissions from power plants would reduce atmospheric sulphate concentrations, thereby increasing radiative forcing and imposing a short-term detrimental effect on the climate. A multi-pollutant abatement strategy that considers how to control various pollutants and sources must therefore be developed.

e) China's INDC Submission

China was the first emerging economy to submit its Intended Nationally Determined Contribution (INDC). It did so on the last day of June 2015. China's submission includes four key points: first, China's emission level is to peak by around 2030 (consistent with the joint announcement China made with the US in November 2014); second, China's carbon intensity (emissions per unit of GDP) is to fall by 60%-65% from the 2005 level by 2030; third, China's share of non-fossil fuel primary energy (including nuclear, renewables, and hydro) is to rise to around 20% by 2030; and, finally, China's stock of forests is to increase by around 4.5 billion cubic meters by 2030.

1.2 GHG emissions: Current levels and drivers and past trends

Over the last decade, the Government of China has recognized climate change as a major issue related to the overall situation of economic and social development, and has incorporated an active response to climate change into its medium and long-term economic and social development plans. In 2006, China introduced an obligatory target of a 20% decrease in energy consumption per unit GDP in 2010 relative to 2005. In 2007 a national plan to combat cli-

3 Particles that measure less than 2.5 micrometres in diameter

mate change among developing countries was developed and implemented. in 2009 China officially pledged to reduce CO_2 emissions per unit of GDP by 40% to 45% from 2005 to 2020 before the United Nations Climate Change Conference (UNFCCC) in Copenhagen (COP15) . Since the 11th Five-Year Plan (2005 to 2010), China has accelerated transformation of its economic development model and has made remarkable progress in controlling greenhouse gas emissions through the implementation of notable measures favouring adjustments of the industrial and energy structure, energy savings, improvements in energy efficiency, and increase of carbon sequestration. During the period of the 11th Five-Year Plan, China achieved its energy-saving targets, with energy consumption per unit of GDP in 2010 dropping 19.1% from 2005, which led to a decrease of CO_2 emissions of more than 1.46 billion tons. In the three years preceding the 12th Five-Year Plan (2011 to 2013), energy consumption per unit of GDP was cumulatively reduced by 9.03% and carbon intensity was reduced by 10.68%. Through the end of 2013, carbon intensity in China has accumulatively declined 28.5% as compared with 2005 levels. Water and electricity capacity has been increased, wind power capacity has been increased, and China leads the world in solar water heater collector area, rural biogas users, and artificial forestation area.

From the period of the 6th Five-Year Plan (1981 to 1985) to the period of the 11th Five-Year Plan (2005 to 2010), energy intensity reduction has always been the leading factor in the decrease of carbon emissions intensity. During the period of the 11th Five-Year Plan, technological renovation and upgrading of traditional light and heavy industries has been constantly strengthened; the intensity of energy per unit of added value in key energy-intensive industries has decreased by 23.4%, 15.1%, 35.8%, and 52%, for iron and steel, non-ferrous metals, petrochemical and chemicals, and building materials respectively; the comprehensive energy consumption of steel per ton, cement clinker, ethylene, and synthetic ammonia have respectively decreased by 12.8%, 12%, 11.6%, and 14.3%; the unit energy consumption of some products has become aligned with international standards; and advanced capacity proportion of high-energy performance of key industries has increased significantly. However, the energy-intensity effect in the period of the 11th Five-Year Plan was relatively weak because of structural effects, whereby potential energy-intensity effects were cancelled out by the sharp rise and subsequent decline in the proportion of energy-intensive industries which followed China's entry into the WTO.

Since 1978, the proportion of added value from primary industry (including agriculture and forest sectors) has continuously decreased in parallel with a continuous increase of the service sector and a rather constant trend of industry sector above 40% (see Figure 1). Compared to developed countries, which have already achieved industrialization, the proportion of the added value from the secondary industry sector (including major industry sectors) in China remains relatively high, and standard economic development theory would anticipate further structural adjustments with a decrease of secondary industry sectors and a rise of third industry (including service sectors in the economy) activities. In addition to technological progress and improvements in energy efficiency, further acceleration of this adjustment in the industrial structure is an important driver for China to reduce CO_2 emissions in the future, given the much lower emission intensity of service activities.

Recently, during the period of the 11th Five-Year Plan, the share of secondary industry sector has decreased from 47.4% to 46.7%, while the third industry sector activity has increased significantly from 40.5% to 43.2%. In addition, during the period of the 10th and 11th Five-Year Plans, the scale of high-tech and new technology manufacturing has expanded unceasingly, but the growth of high-energy-consuming industry has slowed down.

Figure 1. Structural Changes to the Three Industries over the Years in China

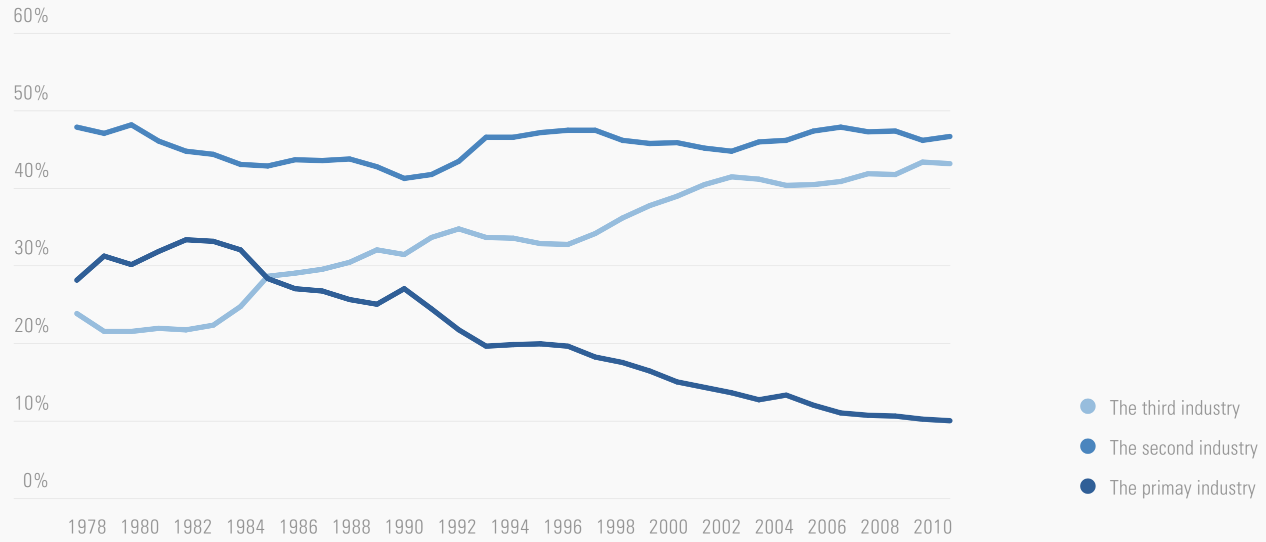
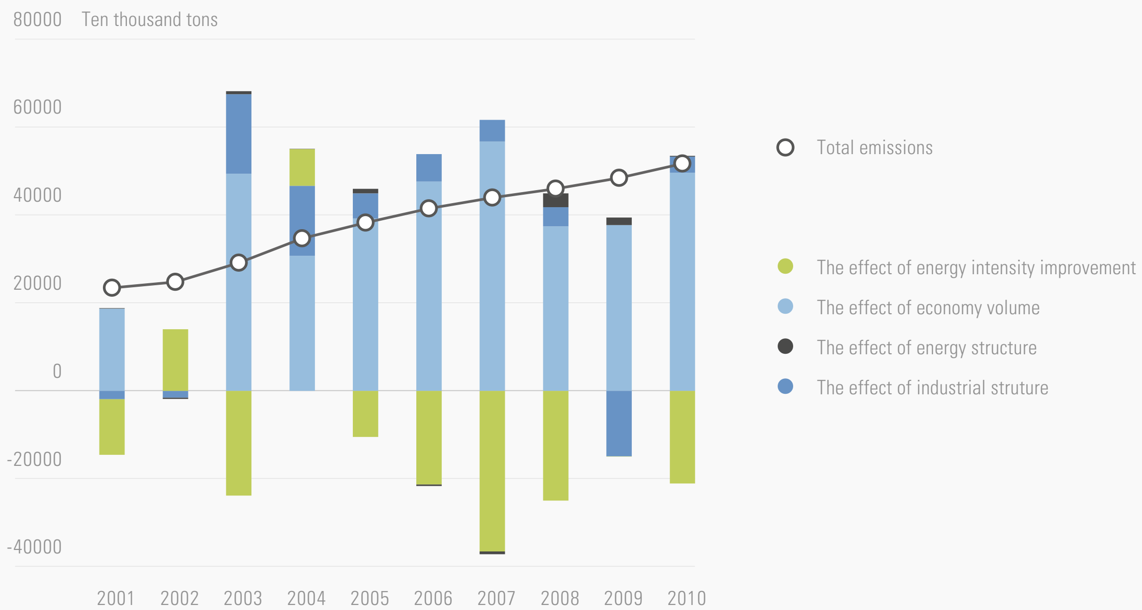


Figure 2. Decomposition of Driving Factors for Carbon Emissions Increase in China (2000 to 2010)



According to the Kaya equation, there are four key driving factors for carbon emissions: Economic growth, economic structure (the shift from energy-intensive sectors to energy-light sectors), energy intensity (energy use per unit of GDP within the sector), and emissions per unit of energy use. The decomposition analysis displayed in Figure 2 shows that, over the period of the 10th and 11th Five-Year Plans, the CO_2 emissions in China increased by 2,853 million tons, with a dominant upward push coming from economic growth (+3,497 million tons) and smaller ones from industrial structure (410 million tons) and energy structure (+36 million tons). However, significant reductions of energy intensity have also provided a significant downward push to national emissions (–1,091 million tons)[4]. Changes in energy structure have had little effect on emissions. Economic growth has always been the key factor affecting carbon emissions, and major improvements in energy intensity only partly offset its effect, which is why we still observe increases in emissions.

2 National deep decarbonization pathways

2.1 Assumptions of economic and social development

China's economic, demographic, and social development – including GDP, population, and urbanization rates – are important drivers of the future emissions pathway. To establish these important parameters, China relies on assumptions from a combination of expert judgment and the relevant literature.

As a developing country, China is still in the progress of industrialization and urbanization and striving to improve the living standard of people, while putting more attention on the quality of economy growth to achieve the sustainable development. In 2014, the economy of China experiences a lowest growth in last 24 years. It is therefore anticipated that China's future economy will enter into a new era described as the "the new normal," an adjustment period during which the country will transition from an input intensive development model to a more sustainable and high-efficiency economic pattern, making it possible to combine rapid and sound economic development with a gradual slowdown of economic growth. This is reflected in the assumptions of GDP per capita in the national deep decarbonization pathway scenario, which average at 4.8% over the period 2010–2050, with a gradual decline of growth rates from 7.2% over the period 2010–2020 to 2.8% over the period 2040–2050 (see second line in Table 1).

We adopt the UN's 2012 population projection as a reference, adjusting it downward in the mid to long term to account the miscalculation in the UN's figures for China's population in 2013 and 2014. The adjusted projected population peaks at around 2030, with a population about 1,420 million and gradually declines to 1,353 million by 2050 (first line in Table 1).

Table 1. Development indicators and energy service demand drivers in China

	2010	2020	2030	2040	2050
Population [Millions]	1,341	1,400	1,420	1,402	1,353
GDP per capita [$/capita, 2010 price]	4,604	8,819	14,504	21,432	29,270
Urbanization rate	49.3%	60%	68%	73%	75%

4 Results are from Tsinghua University, 2014

China's urbanization goes hand in hand with its fast economic growth. The accelerating urbanization process is depicted in a government working report[5] as the most important aspect of social development, enabling the rise of people's living standards and in turn pushing up energy use. As China enters its later stage of industrialization in the near future, urbanization is expected to become the main impetus of energy. Judging from China's urbanization trend and an overview of other relevant research, it is assumed that the urbanization rate of China will rise continuously from its current rate of 49.3% in 2010 to 75% by 2050 (third line in Table 1).

2.2 Illustrative Deep Decarbonization Pathway for China: High-level characterization

The illustrative DDPP pathway is analysed using Strategy Analysis on Climate Change in China model (SACC) developed by National Centre for Climate Change Strategy and International Cooperation (NCSC). It attempts to study China's future energy production and consumption and carbon emissions at 10-year intervals extending from 2010 through 2050. The service demand, energy structure, and energy-related technology progress of end-use sectors, including industry, transportation, and the building sector, are determined by both scenario survey and expert opinion. Power consumption is given by combining the power demand in end-use sectors, and related carbon emissions are calculated by optimizing the technology options for power generation under a cost-minimization condition. The DDPP pathway combines an acceleration of economic structural evolution, effective control of service demand, promotion of low-carbon energy development (including the development of natural gas and non-fossil fuels), and deployment of low-carbon technologies such as carbon capture, utilization, and storage (CCUS) in a context of continued economic growth.

a) Energy trends

As described in the "Two 100-Year Goals"[6] by central government, China is dedicated to building a "moderately prosperous society in all respects" by 2021 as the CPC celebrates its 100th anniversary, and building an "affluent, strong, civilized, and harmonious socialist modern country" by the 100th anniversary of the People's Republic of China in 2049. Against this backdrop, both GDP per capita and absolute GDP are expected to increase by more than 6 times from 2010 to 2050, while primary energy consumption is projected to reach a maximum of about 4,610 MToe[7] around the year 2040 (1.86 times its level in 2010), before a slight decline to 1.76 times (4,358 MToe) the 2010 level in 2050. (The trends for final energy consumption are very similar, with a peak in 2040 at 1.77 times its 2010 level, before a slight decline to 1.62 times its 2010 level in 2050). These trends feature a significant decoupling of energy consumption from economic growth, thanks to China's continuous efforts on energy efficiency, as measured by a 47% and 73% reduction of energy intensity per unit of GDP in 2030 and 2050, respectively.

The industry sector is projected to remain the largest end-use energy consumer over the whole period; its final energy consumption increases by 39% from 2010 to 2050, but it

5 Report on the Work of the Government (2015), delivered at the Third Session of the 12th National People's Congress by Premier Li Keqiang, http://english.gov.cn/archive/publications/2015/03/05/content_281475066179954.htm

6 "Two 100-Year Goals" were two goals first brought forward in the Report to the Eighteenth National Congress of the Communist Party of China, which was delivered by the then chairman Hu Jintao on Nov 8h, 2012.

7 In this report, the conversion of electricity is based on electrothermal equivalent (86.0 toe/Gwh) in final energy consumption and fossil fuel equivalent (which is coal consumption used to per kWh of electricity) for primary energy consumption.

represents a declining share of the economy, from 67% in 2010 to 58% in 2050, as other sectors accelerate their increase in share. Transportation and buildings, the two major sectors closely related with urbanization, will go through enormous increases in energy demand, with final energy consumption in 2050 increasing by 130% and 92%, respectively, from 2010 levels. The shift in energy-use ratio reflects the change in the economic-industrial structure during China's industrialization and urbanization process. However, since China is entering into the later stage of industrialization, the economy structure will become more optimized along with the increasing share of service industry, which is much less energy-intensive. On the other hand, the promotion of people's living standards and expansion of service and consumption needs during China's urbanization process will still generate enormous energy consumption needs, gradually surpassing industrialization as the biggest driver of increased energy use.

Figure 3. Final energy consumption in 2010 and 2050, by sector

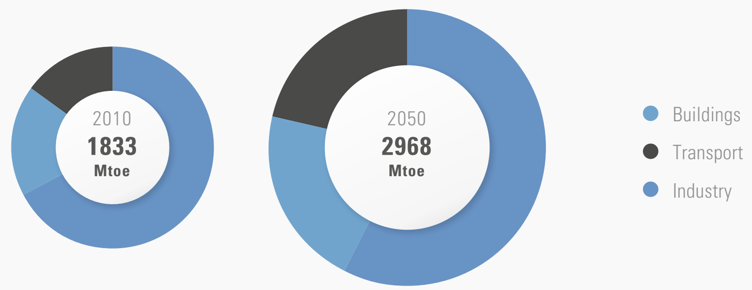
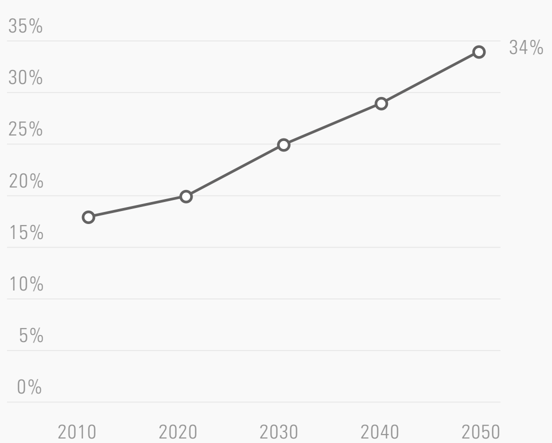


Figure 4. Electrification rate in final energy consumption



Along with the change in economic and industrial structure, the energy mix will be gradually turned towards clean and low-carbon energies. Electricity will gradually become a major energy source with a tripling of electricity consumption, from 3,936 Twh in 2010 to 11,772 Twh in 2050, and the electrification rate grows from 18% in 2010 to 34% in 2050 . In 2050, electricity consumption per capita is projected at about 8700 Kwh, close to the 2010 average level of consumption in developed countries. Non-fossil electricity will dominate electricity production, with the ratio climbing to 72%, thanks to the enormous growth of wind and solar, along with steady growth of nuclear and hydro power. These developments of domestic non-fossil fuels are in line with national targets, reaching about 15% and 20% in primary energy consumption in 2020 and 2030, respectively, and will accelerate once the technologies are mature and affordable, especially after 2030. The ratio of non-fossil fuel in the primary energy consumption is projected to reach 42% in 2050.

As China deepens strategic cooperation with central Asian countries under the "One Belt and One Road" framework and pushes forward national gas and oil pipeline construction projects with Russia and other countries, China's will have a more diversified and secure energy supply of oil and natural gas. With sufficient sources, natural gas consumption under the DDPP pathway will increase to about 8,000 m3 in 2050, accounting for about 17% of primary energy consumption.

Coal use is projected to reach a maximum of around 4.1 billion tonnes around 2020 and to plateau for about 10 years before experiencing a decrease in parallel with rapid development of non-fossil fuels and natural gas. In 2050, the proportion of coal in primary energy consumption is projected to drop to 27% in 2050, about the same level as in the US and Germany in 2010.

b) Energy-related CO_2 emissions and their drivers

Under the DDPP pathway, energy-related CO_2 emissions continue to increase and reach their peak level at around 11.5 $GtCO_2$ around 2030 before decreasing to 5.2 $GtCO_2$ at 2050, 37% lower than the 2010 level. We can also decompose energy-related CO_2 emissions by their 'Kaya' drivers, i.e. GDP, primary energy per unit of GDP, and energy-related CO_2 emission per unit of energy. The increase by a factor of 6.4 times GDP is offset more by the 73% reduction of energy intensity of GDP and 63% reduction of carbon intensity of fuels and the CO_2 emission in 2050 falls to 63% of 2010 level. From this decomposition, it can be observed that China's deep decarbonization plan relies on strong action regarding both of these pillars. It can be noted that, although the magnitude of the two effects is rather close in

Figure 5. Electricity consumption per capita in major developed countries, 2010

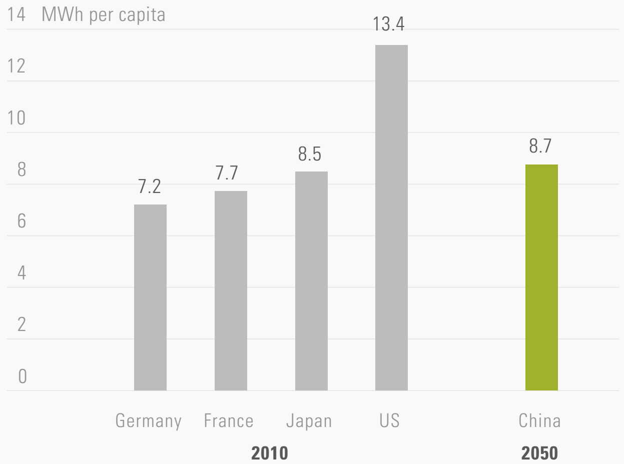


Figure 6. Primary energy use in 2010 and 2050, by fuel type

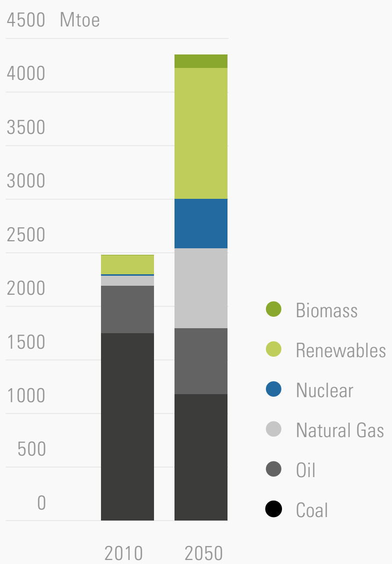
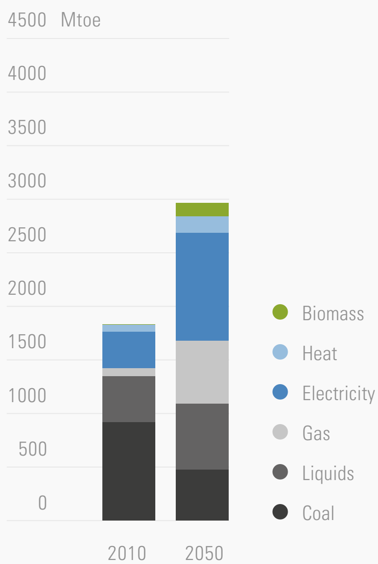


Figure 7. Final energy use in 2010 and 2050, by fuel type



aggregate from 2010 to 2050, the time profile of these actions is very different. Indeed, on the one hand, energy efficiency operates in a rather homogeneous manner across the four decades (around 25% improvement every ten years). On the other hand, reduction of CO_2 intensity per energy use is very marginal until after 2030, when it begins to play a crucial role – especially after 2040, with an approximately 40% reduction over the past 10 years of the period, when all decarbonization options are operating at full scale.

Reduction of carbon intensity is essentially enabled through the electrification of end-uses in parallel with decarbonization of power, which results in a combination of non-fossil sources and application of CCUS in the power sector, both of which reach critical potential after 2030. Altogether, CO_2 emissions per unit of electricity generation will be around 68 gCO_2/kWh in 2050, a more than 90% reduction from 2010 levels (see section 3.1 for more in-depth discussion).

The application of CCUS technologies in power generation and industry sectors is instrumental for achieving deep emission reductions after 2030 and are one of the major sources of the acceleration of decarbonization after 2030. Research, demonstration, and commercialization of CCUS are to be steadily promoted, and the commercialization of CCUS technologies is projected to start in 2030. In 2050, CCUS is projected to help achieve an annual net removal of around 2,737 $MtCO_2$ (870 $MtCO_2$ in industry sector and 1,867 $MtCO_2$ in power generation sector), — 32% less than that in the absence of CCUS.

The reduction of energy per unit of GDP is another crucial parameter for the achievement of the decarbonization pathway in China, and optimization of the industrial structure is a most important contributing factor to this evolution. The transition from an investment-driven growth mode to an efficiency-improvement-driven growth mode should be anticipated in the medium term in China. Both the optimization of economy structure among primary, secondary, and tertiary industries and internal structural optimization within the secondary industries are needed to decrease the energy intensity of economic development. In the DDPP scenari-

Figure 8. Ten year variation rate of emission drivers

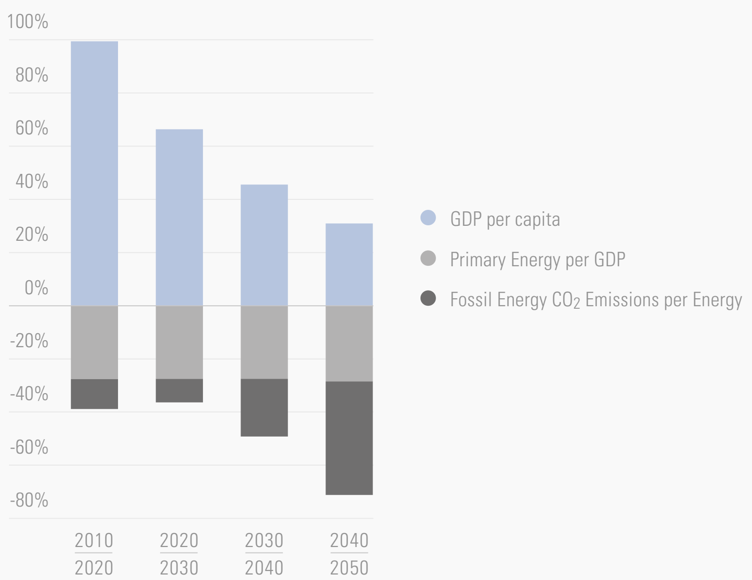
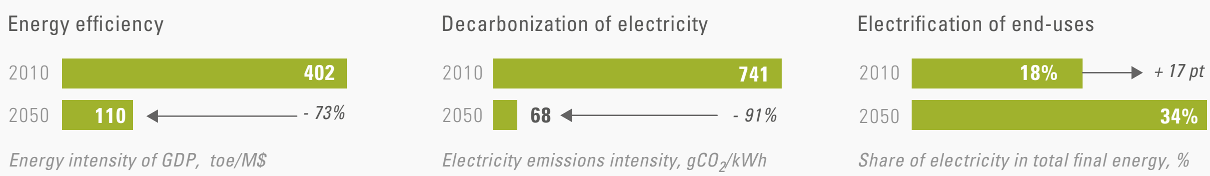


Figure 9. The pillars of decarbonization



os, the share of primary, secondary and tertiary industries in 2050 is expected to be adjusted to a ratio of 2.2%/32.5%/65.3% from 2010's 9.6%/46.2%/44.2%, meaning a large decrease in energy-intensive industries and increase in low-carbon service sectors. Mainly to this restructuring, the energy intensity per unit of GDP will see a significant reduction, to 110 toe/M$ (2010 price) in 2050, 73% lower than that of 2010.

3 Characterization of sectors

3.1 Power sector

Electrification is an important indicator of economic and social development, and is expected to increase significantly as China closes the gap with developed countries in both economic and social development. Under the DDPP scenario, electricity consumption is projected to reach 11,772 TWh in 2050, or 8,700kWh per capita (around three times the 2010 level), which is about the same current level of major developed countries (7215, 7734, 8490 kWh for Germany, France, and Japan in 2010 as shown in Figure 3). The electrification rate in China will increases from 18% in 2010 to 34% in 2050.

Fossil fuels (coal, gas, and oil) are the source of 80% of total power generation in 2010, with a dominant role played by coal, which makes the power sector an important source of both GHGs and local air pollutants. Considering the increasing scale of electricity in China's final energy consumption, decarbonization of the power sector is a crucial component of any pathway for the achievement of low-carbon development.

Under the DDPP scenario, the development of non-fossil energies is consistent with the announced 2020 and 2030 targets and accelerates after 2030, when low-carbon technologies are more mature and costs have been decreased sufficiently by cumulative research and development to make them competitive with respect to traditional thermal power. The share of non-fossil power in total power generation rises from less than 20% in 2010 to 34% in 2020, 43% in 2030, and 72% in 2050. Measured in total primary energy consumption, non-fossil energy accounts for 15% in 2020, 20% in 2030, and 42% in 2050.

Hydro-power remains the most important renewable power supply before 2020, accounting for more than 52% of non-fossil power generation and 65% of renewables; then, because hydro-power has already been exploited widely, the growth rate of hydro capacity would slow down and the proportions will gradually drop to 20% of non-fossil power and 27% of renewables in 2050, and the installed hydro-power capacity is projected to be about 500 GW in 2050. With more stringent safety standards and requirements, nuclear capacity is expected to grow; however, as a result of constraints on water availability, nuclear power sites are limited to locations near rivers and seas, and installed nuclear power capacity in 2050 is projected to reach 320 GW, accounting for 27.6% of total non-fossil power generation. The intermittent renewables, especially wind and solar, could see major leaps with enough incentive measures and infrastructure construction. By 2050, wind power capacity will be nearly 1200 GW, responsible for 26.8% of total non-fossil power generation, and solar power capacity will be over 1200 GW, contributing 21.7% of non-fossil fuel power generation.

Figure 10. Variation of CO_2 intensity of electricity over time, by type

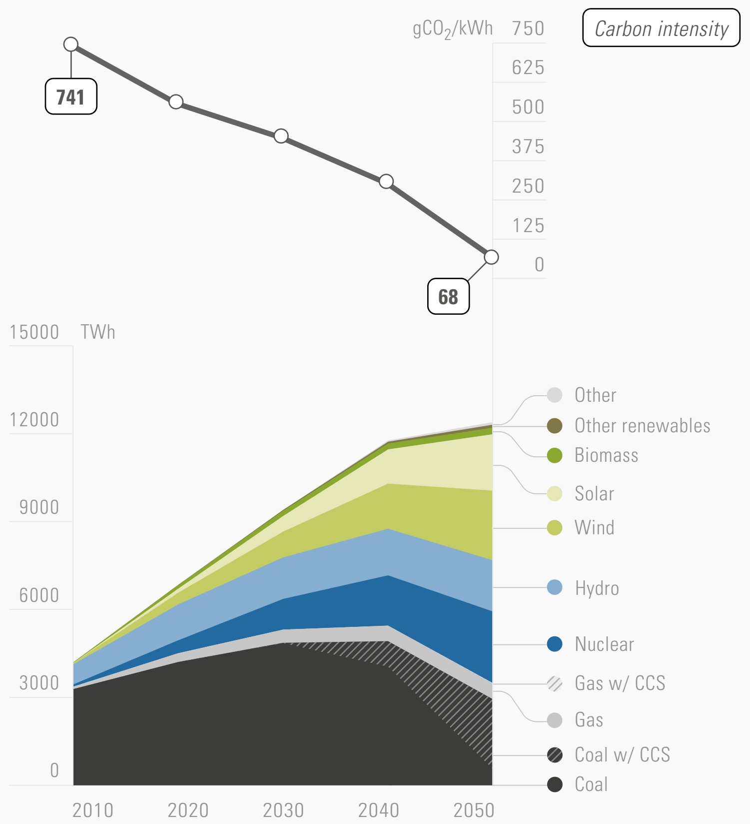
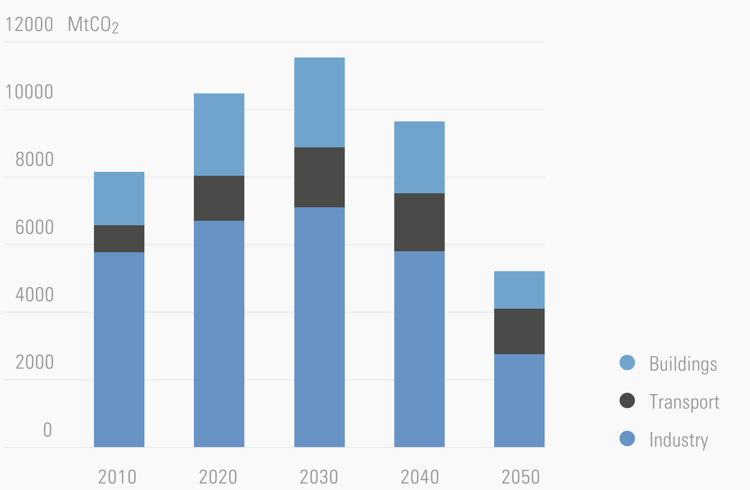


Figure 11. Energy-related CO_2 emissions by sector from 2010 to 2050



CCUS serves as an important measure to reduce emissions from the power sector after 2030. By 2050, CCUS facilities are expected to be installed in about 75% of capacity stock of coal power plants, and the annual storage of CO_2 in the power sector will reach more than 1.8 $GtCO_2$.

Finally, fossil-based emissions are also reduced by a large percentage due to the deployment of efficient technology options (notably, all new coal power plants after 2020 will be supercritical, ultra supercritical, or IGCC power-generation technologies).

Thanks to the uptake of non-fossil power, the application of CCUS, and efficiency measures in the remaining fossil-powered power plants, the carbon emission intensity of power generation will largely decrease in 2050, from 741 g CO_2/kwh in 2010 to 68 gCO_2/kwh.

3.2 End-use sectors

At the sector level, by 2050 the emissions of the industry sector decrease by about 52% from 2010 levels, but this sector is projected to remain the largest source of emissions, accounting for 53% of national emissions. Emissions from the transportation sector increase by 67% over the period 2010 to 2050, whereas those of the building sector decrease by 30% over the same period. And the emissions trends of both transportation and building sectors represent a significant decoupling from final energy use given the 130% and 92% projected increase in final energy use in these two sectors respectively, which is enabled through electrification of end uses and increasing the ratio of non-fossil fuels in the overall energy mix.

a) Industry

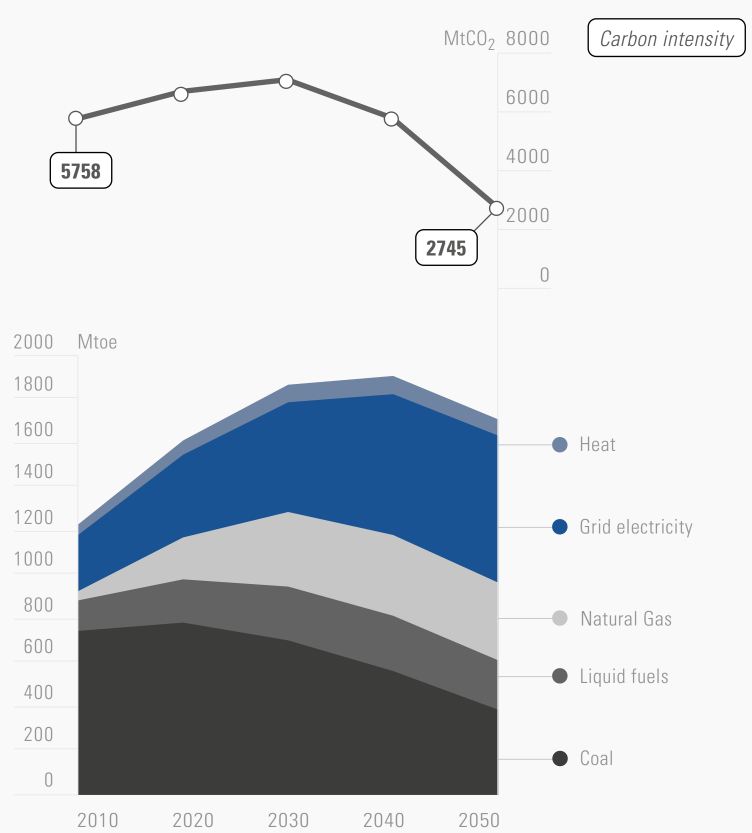
As a main sector driving economic growth, the industry sector accounts for almost 67% of final energy consumption and almost 71% of total energy-related CO_2 emissions in 2010. Decarbonization of industry sectors is crucial to the overall decarbonization of China. Implementing deep decarbonization in the industry sector relies on a combination of improved energy efficiency, fuel switching, economic structural adjustment, along with internal structure optimization inside industry sector and the deployment of CCUS.

Energy efficiency in industry sectors is improved to a large degree through the application of energy-saving technologies, high-efficiency heat-recycling technologies, and high-efficiency boilers and motors. Through technological innovation, energy consumption per value added of the industry sector is reduced by 75% from 2010 to 2050, reaching the present average level of the European Union. Thanks to these improvements, the 39% increase of final energy consumption over the period 2010 to 2050 (from 1233 Mtoe to 1709 Mtoe) remains moderate, especially when considering that value added of the industry sector increases by 428% over the same period. By 2050, energy consumption per unit of product output of energy-intensive industries reaches the advanced efficiency level of international standards with reductions of 53%, 26%, 20%, and 19% from 2010 to 2050 in iron and steel, cement, synthesis ammonia, and ethylene production, respectively (these four industries together account for about half the total energy use in the entire industry sector)

By promoting the transformation of coal-fired boilers to gas-fired boilers and enhancing the use of electricity, the share of gas and electricity for energy end use in the industry sector increases from 3% to 21% and 21% to 39%, respectively, while coal use decreases from 61% in 2010 to 22% in 2050. Particularly, the core of the shift from coal to electricity is expected to happen after 2030 because, until then, power generation will remain essentially fossil-based and therefore electricity would be more carbon-intensive than direct coal use.

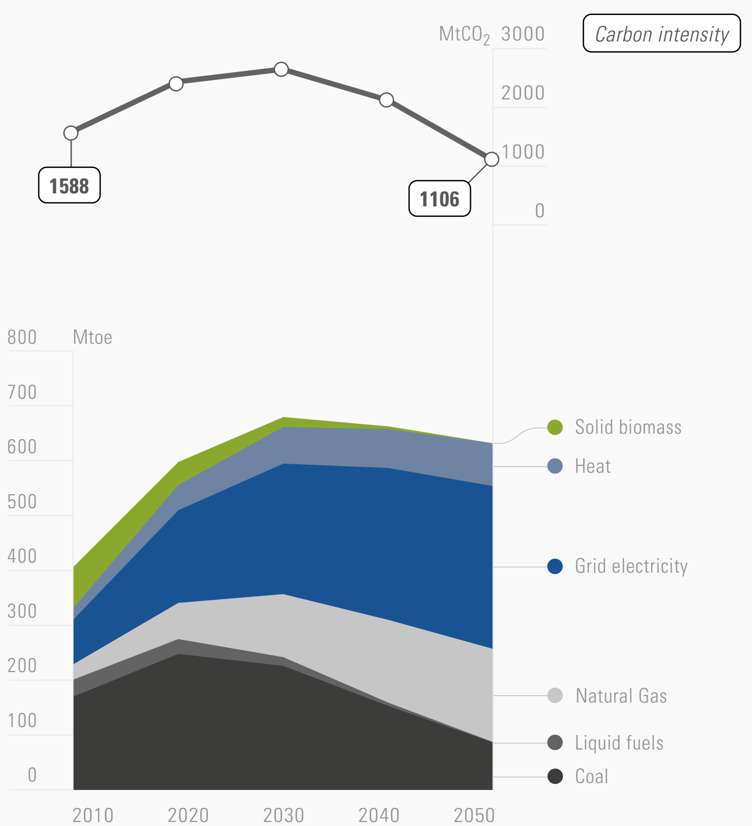
In addition, when the tertiary industry grows fast, from 44.72% of total GDP in 2010 to about 65% at 2050, the secondary industry decreases gradually from 46.2% to 32.5% (close to the share in Germany in the mid-1990s and the world average in the early 1990s). Notably, many energy-intensive industry sectors will experience slower growth, and the output of some energy-intensive industry products (notably, cement and crude steel) are anticipated to peak by 2020. The development of tertiary industry in parallel helps China to promote economic development while decreasing energy consumption and CO_2 emissions. Besides, structural changes within the industry sector can be realized that will help cut

Figure 12. Final energy consumption by fuel for industry sector



down CO_2 emission: notably, the development of strategic industries, like energy-saving and environmentally friendly industries, new energy industry and upgraded information technology, the control of overcapacity in main industry outputs in iron and steel and cement sectors through improvements in examination and approval systems, and the phasing out out-dated production capacity by raising standards for industrial equipment and production capacity.
The deep decarbonisation pathway for the industry sector also relies on the large-scale deployment of CCUS. If CCUS is deployed appropriately on a commercialized scale after 2030 in key industry sector, it is expected to capture 20% of total CO_2 emissions in the industry sector in 2050, 70% of which occurs in energy-intensive industries (cement, iron and steel, chemicals, and petrochemicals).
Thanks to these combined measures, the CO_2 emissions per unit of energy consumption of the industry sector will be reduced by 70% in 2050 (half the current level in the European Union). CCUS is a crucial factor in this projection, since the reduction in CO_2 emissions per unit of energy consumption in the industry sector would only reach 50% in the absence of CCUS. The projected result of CCUS deployment is that CO_2 emissions from fuel combustion in industry sector peaks around 2025 at about 7.2 $GtCO_2$ and decreases to less than 2.7 $GtCO_2$, nearly 52% lower than the 2010 level.

Figure 13. Final energy consumption by fuel for building sector



b) Building

The building sector accounts for about 18% of total final energy consumption and 19% of carbon emissions in 2010. Triggered by a rising standard of living and increased service demand triggered by the urbanization process, both the total floor area and the intensity of energy consumption are expected to experience a steady growth over the next decades in the building sector, serving as an important driver for China's energy and emission growth.
In DDPP scenario, China's huge population and limited natural resources make it imperative for China to temper its growth mode during the urbanization process. By launching effective policies and regulations and promoting a low-carbon lifestyle, the total floor area will continue to rise but the growth will be constrained at a relatively low level, with public building area per capita and residential building area per capita reaching about 13 m^2 and 37 m^2, respectively in 2050, similar to current levels of growth in major EU countries (Germany, France).
Energy-efficiency improvements play an important role in limiting the rise of energy demand

and CO_2 emission in the building sector. Energy efficiency for buildings will be improved by both continuously retrofitting of existing buildings with energy-saving features and increasing the proportion of green and low-carbon building in newly constructed buildings. In DDPP scenario, while most (>90%) of existing buildings being retrofitted before 2050, all the newly constructed buildings will be enforced to be built according to the latest standards for energy saving after 2020. The thermal insulation of heating pipeline network also will be significantly improved. By all these means, the energy consumption for heating per unit area in northern urban areas will be reduced by half from 2010 to 2050. Thanks to the development of energy-efficient cooling systems, lighting system, and appliances, there will be significant improvement to the efficiency of household appliances. For example, the energy efficiency of regular and central air conditioners would increase by 66% and 75% from now to 2050.

The energy mix will also be greatly optimized. Clean and low-carbon energies, including heat, natural gas, electricity, and distributed renewables will be popularized and implemented. Electricity will become the major types of energy, accounting for 47% of final energy use, of which about 57% is used for specific uses including appliances, cooling and lighting and 43% for substitutable uses including heating, hot water supply and cooking, and natural gas increases to 27% of final energy, with both energy types showing a significant increase from their 2010 shares of usage (24% for electricity and 8% for gas). At the same time, the proportion of coal in final energy consumption is expected to decrease from 42% in 2010 to 13% in 2050.

An important point to keep in mind is that an important part of China's emissions are linked to the process of early demolition of buildings[8]. China's buildings have an estimated average lifetime of 30 to 40 years, much shorter than their international counterparts. Early demolition of buildings and infrastructures increases rates of material intensity and embodied energy, and will be a source of increasing emissions during China's urbanization process if not properly handled. Therefore, it is necessary to implement measures such as better urban planning and strict regulations to reasonably control the demolition of buildings and other infrastructures, so as to reduce material consumption intensity and improve the reuse of waste construction materials. Final energy consumption in the building sector continually rises to 659 Mtoe in 2030 and then gradually falls to 632 Mtoe in 2050, which are, respectively, 2 and 1.9 times the 2010 levels. At the same time, total carbon emissions from the building sector peak around 2030 at 2652 Mt CO_2 and then significantly decrease in 2050 to about 1106 Mt CO_2, 30% lower than in 2010, notably due to electrification and the rapid decarbonization of the power generation sector, as discussed in section 3.1.

c) Transport

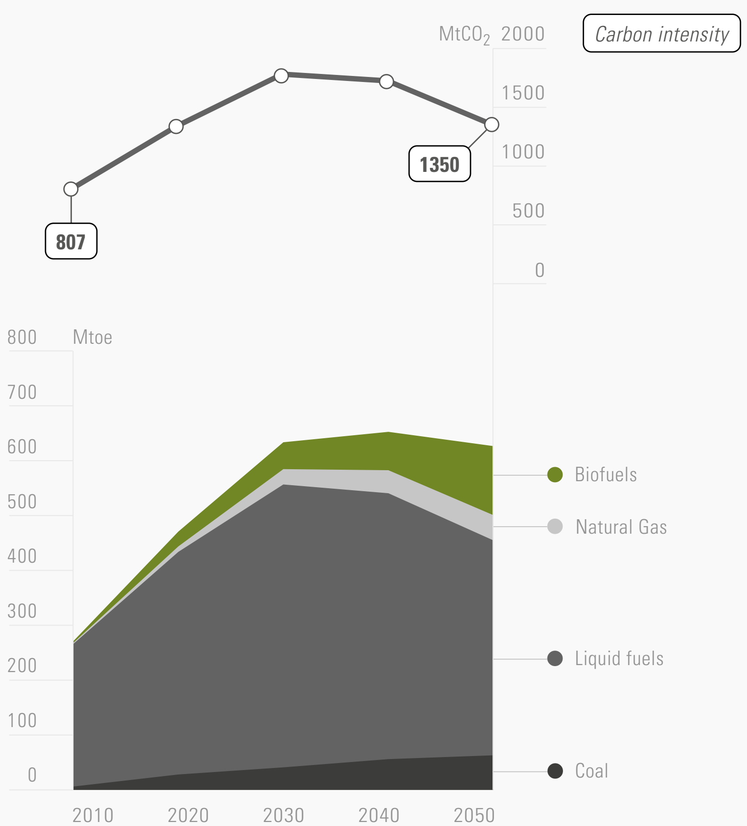
The transport sector in 2010 accounts for 15% of total final energy consumption and 10% of total energy-related CO_2 emissions in 2010. Accompanying the increased demand for mobility and rising living standards, transportation demand is expected to rise quickly. It is therefore crucial to control the energy use and carbon intensity of the transport sector in order to achieve the low-carbon development of China. In general, the achievement of low-carbon transport relies on a shift in the transport sector's structure, improvements in energy efficiency, and optimization of the energy structure.

8 A rough estimation made by China Academy of Building Research shows that the demolition and construction process accounts for about 1.5% of national emissions, and that embedded emissions for materials is above 10%.

Low-carbon modes of transportation, such as rail and water transport, should be encouraged to help achieve low-carbon transportation development. For freight transportation, water transport is encouraged and extended in the future, and accounts for 45% in 2050 of total freight transportation[9]. Railway transportation would remain the main transport mode for passengers, and will account for 25% in 2050 of total passenger mobility, up from 18% in 2010. Public transit and slow-traffic systems (including bicycles, walks and related infrastructure) must be developed in large- and medium-scale cities, and the number of public transit vehicles per ten thousand people in 2050 will reach to 12, nearly three times higher than in 2010.

Energy efficiency is improved significantly through the application of Electronic Toll Collection systems, higher-quality fuel[10], more efficient engines, and intelligent vehicle dispatch systems. Vehicular fuel economy will be increased by a large degree, as illustrated by the reduction by a factor of three of the average fuel consumption of light-duty vehicles (which will reach 2.5 litres of gasoline per 100 km by 2050). Technology innovations in the transport sector help to optimize the energy structure. In railway transportation, the electrification of railway system will increase rapidly and extend to more than 90% of the system by 2050, from less than 50% in 2010. Biofuels, such as non-grain fuel ethanol and bio-diesel, will largely replace gasoline or diesel largely starting in 2020, and biofuels would account for 20% of total energy consumption in 2050. The share of gasoline and diesel vehicles significantly decreases by 2050 because of the increasing adoption of alternative-fuel vehicles, such as 100% electrically powered vehicle (EPV), plug-in hybrid electric vehicle (PHEV), and fuel-cell vehicles (FCV), which are expected to be commercialized by 2030. EPVs and FCVs would account for 60% of passenger car stock in 2050,

Figure 14. Final energy consumption for the transport sector, by fuel



9 The water transportation turnover accounts for 48% of total freight transportation in 2010.

10 Higher quality fuels mean that the quality of gasoline or diesel would be improved to a higher level, such as the lead content could be decreased in the future.

11 The electricity here is accounted by calorific value calculation, not coal equivalent calculation. If the later method was used, the share would be reached to around 15%. The electricity consumption in 2050 in DDPP scenario will be 535 TWh, which is more than 20 times than that in 2010, however, 535 TWh is equal to 46 Mtoe, if account method is calorific value calculation, and while the total energy consumption in transport in 2050 is 627 Mtoe. And on the other hand, in transport sector, the freight transport consumes the main share of energy consumption, and it main consumes liquid fuels, for example, the liquid fuel consumed in freight transportation in 2010 could account for 74% of total final energy consumption in transport sector.

and electricity consumption in the transport sector will see rapid growth, from 24 TWh in 2010 to 535 TWh in 2050, accounting for only 7.3%[11] of total final energy consumption in 2050.

The total final energy consumption of the transport sector will rise gradually and peak at 653 Mtoe around 2040, then gradually fall to 627 Mtoe in 2050, 2.4 and 2.3 times their 2010 levels, respectively. The energy-related carbon emissions of the transport sector peaks at 1.78 Gt CO_2 around 2030, nearly 15% of total energy-related CO_2 emissions. The CO_2 emissions intensity of energy consumption in transport will be reduced by 30%, from 3.0 tCO_2/toe in 2010 to 2.1 tCO_2/toe in 2050.

4 Key factor analysis

4.1 Replacing coal with electricity

Using electricity to replace coal is seen as an effective carbon emission reduction choice in the long term. However, whether this is an efficient strategy to reduce CO_2 emissions depends on the CO_2 emission per unit electricity consumption, as determined by the electricity-generation structure. Without deploying any CCUS, electricity is less carbon-intensive than coal only when the share of fossil fuel in total electricity generation is less than 33% (the proportion of coal-fired and gas-fired electricity generation in the total electricity mix). Regardless of whether or not CCUS are deployed, replacing coal with electricity will help to cut down CO_2 emissions as long as the CO_2 emission per unit of electricity consumption is less than 0.31 $kgCO_2$/kwh.[12]

In the DDPP scenario, the share of fossil fuel in total electricity generation is about 57% in 2030 and decreases to about 44% in 2040. In the DDPP scenario, the CO_2 emissions per unit of energy provided by electricity is 2.5 times higher than direct coal in 2010; this number decreases to 1.5 in 2030, and passes below 1 just before 2040 (0.96 in 2040) before declining further to 0.2 in 2050, with large-scale deployment of CCUS. Without any CCUS, the number in 2050 will instead be 0.4. Therefore, in the DDPP pathway, replacing coal with electricity in the industry sector becomes an adequate strategy to reduce carbon emissions in the late 2030s.

This trade-off is tested in the following two sensitivity analyses.

4.2 Electrification rate of the transport sector

The electrification rate of the transport sector in 2050 can increase faster than that planned by the Central DDPP scenario by applying more EPVs and FCVs, if appropriate policies and supporting measures are implemented. In addition to the policies already in place, such as the "energy efficiency and development of a new-energy-vehicle industry" plan, new policies, innovations, and measures will be launched to promote the development of EPVs and FCVs. These can include preferential policies, like increased subsidies for buying or using EPVs or FCVs, exempting EPVs and FCVs from the lottery for car plates, low or no highway tolls for EPVs and FCVs, etc. Technological improvements will be crucial, notably regarding energy-storage

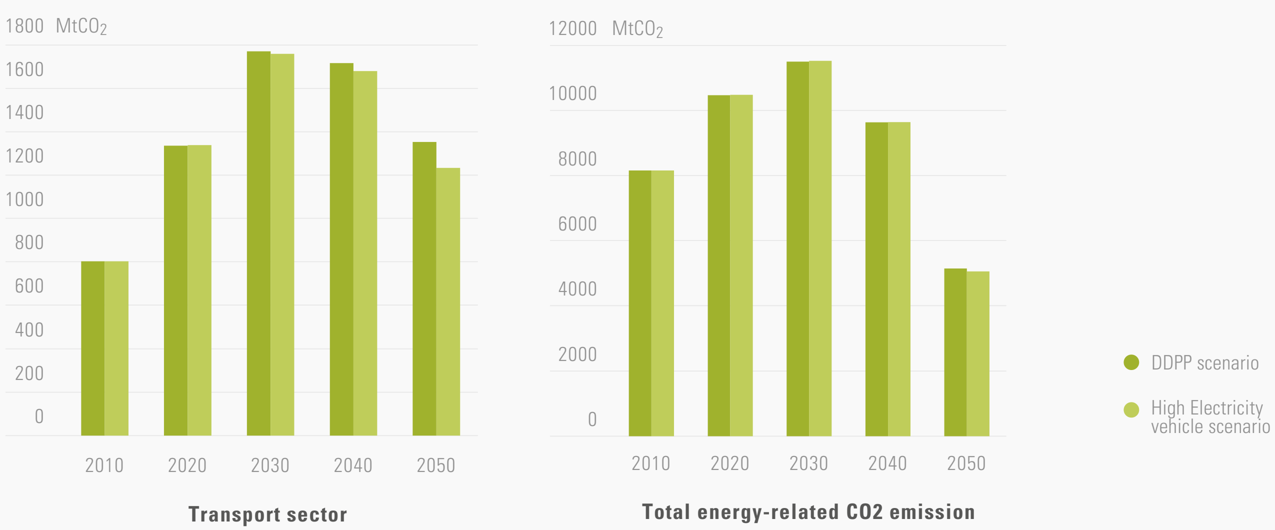
12 We compare the CO_2 emission per unit of energy consumed by coal and electricity by a simple calculation of multiplying the emission factor of coal (around 2.5 gCO_2/gce) by the standard coal coefficient of electricity (0.1229 gce/kwh).

technologies, charging times of batteries, and driving distance autonomy, as well as development of infrastructure for electricity charging. Considering all of these factors, researchers at the Energy Research Institute (ERI) and the China Automotive Energy Research Centre predict that it is possible that the combined share of EPVs and FCVs as a percentage of the total fleet could be increased to 80% (instead of 60% in the DDPP scenario. Meanwhile, the ratio of FCV in freight and intercity passenger transportation turnover can be further increased by 5 percentage points (from 15% to 20%) and 10 percentage points (from 20% to 30%) respectively. Considering all these efforts (the High Electricity vehicle scenario), the electrification rate in the transportation sector can increase to 10%[13] in 2050, which means the total final energy consumption can be further reduced by 32 Mtoe. The comparisons of CO_2 emissions in the DDPP scenario and the High Electricity vehicle scenario are shown in Figure 14. Total CO_2 emissions of the transport sector under the High Electricity vehicle scenario are 1238 Mt in 2050, 3% lower than that in the DDPP scenario (which calls for a reduction of 112 Mt CO_2). Total CO_2 emissions in the High Electricity vehicle scenario are 5103 Mt, 1.9%lower than that in DDPP scenario (reduction of 98 $MtCO_2$). Under this condition, the CO_2 emission intensity of energy consumption in transport could be further reduced by 5% (from 2.1 tCO_2/toe to 2.0 tCO_2/toe) in 2050.

4.3 The development of CCUS

CCUS is of great significance in the medium- and long-term carbon emission reduction of China, avoiding 1.2Gt and 2.7 Gt CO_2 emissions in 2040 and 2050, equal to 9.6% and 31.8% of total emitted emissions in 2040 and 2050, respectively. From 2010 to 2050, the accumu-

Figure 15. CO_2 emission comparison between DDPP and High Electricity vehicle scenario



13 The electricity consumption in 2050 in High Electricity vehicle scenario will be 666 TWh, which is about 130 TWh higher than that in DDPP scenario. 130 TWh is equal to 11.2 Mtoe if using calorific value calculation. And the total energy consumption in High Electricity vehicle scenario in 2050 is about 595 Mtoe.

lated CO_2 capture is around 27Gt CO_2. However, the development of CCUS faces important uncertainties regarding storage capacity, technology, policy, and cost.

Theoretical capacity of different storage potentials is very important (see Table 2). However, there's a gap between the theoretical capacity and the practical capacity given several restrictive factors, like CO_2 transportation distance, cost, and local environment and resources. Based on the studies conducted by the Institute of Rock and Soil Mechanics at the Chinese Academy of Sciences, the total predicted practical capacity is from 10GtCO_2 to less than 100 Gt CO_2, which, in terms of potential capacity of storage per year, is equal to 0.1GtCO_2 to 1GtCO_2 for enhanced resource utilization and around 1 GtCO_2 of CO_2 for geological under the assumption that the total capacity is fulfilled in 100 years. This is the estimate we use as the basis for our setting of CCUS annual storage capacity under the DDPP scenario.

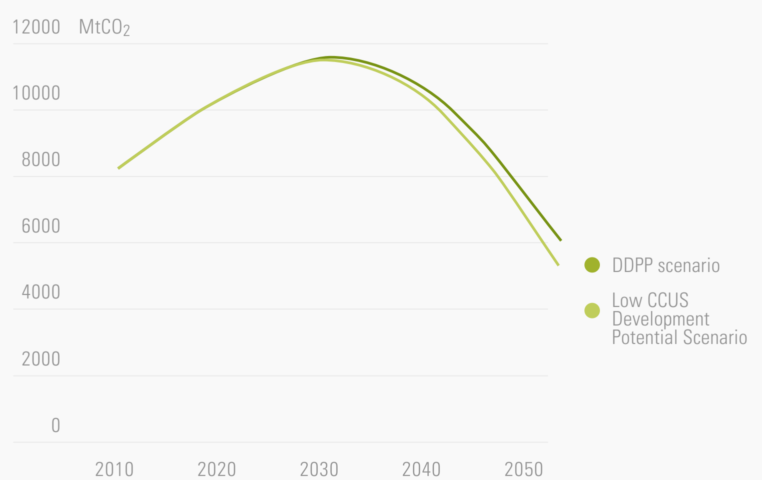
CCUS projects are now only in the demonstration phase for Carbon Capture+ Enhanced Oil Recovery (EOR), or are envisaged but not started yet for Enhanced Coalbed Methane (CO_2-ECBM) and CO_2-Enhanced Water Recovery (CO_2-EWR). Therefore, it is still uncertain whether CCUS technologies can experience a large-scale deployment by 2030, especially since some technical problems like source-sink matching and additional energy consumption incurred by carbon capture must be considered. These uncertainties create the possibility that CCUS projects might be postponed and that the long-term emission-reduction potential of CCUS might be diminished. We consider a variant in which the CO_2 storage capacity might be reduced by around 1 GtCO_2 per year in 2050 by expert consultation and and relevant literatures.

The Chinese government has attached much importance and put strong effort into CCUS research and demonstration, including the release of Notice on Promoting the Experiment and Demonstration of Carbon Capture, Utilization and Storage in 2013 and providing financial support to several key national projects on CCUS research and demonstration. However, an effective and complete policy system to support the long-term development of CCUS is still lacking, since China has neither formed a clear policy direction for the development roadmap of CCUS nor formulated directly supporting policies. To make possible the long-term development of CCUS at the scale required for deep decarbonization, an adequate policy environment must be deployed, including economic incentives (including carbon pricing), planning (roadmaps), environmental risk monitoring, and control regulations

Table 2. Theoretical potential of different CO_2 storage approaches

Storage approach	Potential
Enhanced Oil Recovery	2-1.92 GtCO_2
Enhanced Coalbed Methane	9.9 GtCO_2
Enhanced Gas Recovery	5.2 GtCO_2
Enhanced Shale Gas Recovery	1.8 GtCO_2
Enhanced Geothermal System	7862.0 GtCO_2
CO_2-enhanced Water Recovery	119.2 GtCO_2
Storage in Deep Saline Formation	3066.0 GtCO_2

Figure 16. CO_2 Emission comparison between DDPP and low CCUS development potential scenario



Regarding cost, the emission sink potential of CCUS is set based on an assumption of carbon price of $70/ tCO_2$ in DDPP scenario. It can be questioned whether such carbon price levels can be reached soon enough (i.e., within the next decade) but CCUS deployment can also be promoted under low-carbon prices by virtue of EOR if the revenue from the recovered oil exceeds the cost of CO_2 transport and storage, making the net cost of CCUS+EOR negative. [14],[15]

In addition to the above-mentioned uncertainties, the development potential of CCUS also relies on the construction of relevant infrastructure, such as carbon transportation pipelines.

In light of the uncertainties regarding storage potential, technology, policy, and cost, the more realistic storage capacity of CCUS will be around 1.5 $GtCO_2$ per year (instead of 2.7 Gt CO_2 per year) by 2050 and CCUS technology will be applied more widely in EOR, with some application in deep saline formation storage. Under this assumption, the total CO_2 emission in 2050 is expected to be 843.4 $MtCO_2$ higher than in the DDPP scenario (15% Mt higher, see figure above).

5 Challenges, opportunities, and enabling conditions

The DDPP pathway demonstrates a potential low-carbon pathway for China's social and economic development. However, considering both international and domestic circumstances, there are still a number of uncertainties and challenges to the achievement of the DDPP scenario in China must be highlighted.

a) GDP growth.

GDP growth is an important parameter determining energy consumption needs and CO_2 emissions, and realization of peak CO_2 emissions requires that the decrease of CO_2 emissions per GDP must be higher than increase of the GDP growth rate. China saw an average GDP growth above 10% during 1990 to 2010, which gradually fell to 7% in 2014 – the lowest in the past 24 years. Considering that China is now entering an "economic new normal", expectations regarding China's future economy growth are still controversial. The Chinese central government is confident of maintaining a GDP growth rate around 7%, which will be still much higher in the future than that of developed countries. (The GDP growth rate in developed countries varies from 2% to 3%). In order to achieve CO_2 emission peak by 2030, it is necessary to transit to a low-carbon pathway that emphasizes quality of life rather than speed of development.

b) Future adjustment of the industrial structure and change of development mode.

China's energy consumption per unit of GDP is twice the average level of the world, which means there is a significant potential for the reduction of energy intensity. However, the decline cannot depend only on improvement of technology development. Notably, energy-intensive industries in China feature a relatively low-efficiency gap with developed countries (10% to 20%). Therefore, the reduction of energy consumption per GDP in China would rely essentially on adjustments to the industrial structure and

14 R.T. Dahowski, et al. Pacific Northwest National Laboratory. A $70/Tco2 Greenhouse gas mitigation backstop for China's industrial and electric power sectors: insights from a comprehensive CCS cost curve. 2012

15 R.T Dahowski, et al. Pacific Northwest National Laboratory. Examining CCS deployment potential in China via application of an integrated CCS cost curve. 2013

changes in the mode of development towards light industry and the service industry.

However, export manufacturing goods have been an important component of China's economic growth, responsible for about 25% of energy consumption. Given that adjustments to the structure of exports are not an easy task, manufacturing exports (and associated emissions) are expected to remain important in the long run. Resolution of these uncertainties regarding carbon emissions reductions requires further investigation.

c) Decrease of emissions factor of per unit energy consumption.

As shown in the foregoing analysis, the rapid development of non-fossil fuel and natural gas play important roles in lowering the emissions factor of per unit energy consumption. China has declared its non-fossil fuel development target to be 20% of primary energy in 2030, which means that 800-1000 Mtoe fossil fuels will be replaced with non-fossil fuels by then. After 2030, most hydro power resources will have been exploited and the further increase of non-fossil fuel will mainly depend on wind, solar energy, and nuclear power. Sustainable development of wind and solar must resolve issues such as long-distance transmission of power and power grid stability with a high ratio of renewables, and the development of nuclear also confronts barriers such as safety concerns. Such a rapid pace of growth in the development of non-fossil fuels development can be sustained only by continuing supportive policies and enhancing the implementation of such policies.

d) Controlling the increase of service demand during China's urbanization process.

China's per capita energy consumption remains significantly lower than the level of developed countries (one-third of the US level and 60% of the levels of Europe and Japan), as a result of different lifestyles and lower living standards. Energy consumption and emissions per capita will increase in parallel with the urbanization process in China. China's population is expected to continue growing in the next 15 to 20 years, and with a substantial segment of the population migrating from rural to urban areas in order to pursue better living conditions. In this context, if the service demands in building and transportation sector are not properly guided, energy consumption and emissions will increase at a faster pace, resulting in a later peak of CO_2 emissions and higher overall levels of CO_2 emissions. Under the DDPP pathway, the average floor area per capita will not exceed the level of major EU countries, and car ownership will be about half the level of Japan. Effective controls of such trends will not be easily realized and will require effective rules, regulations and markets and guiding and the promotion of a low-carbon life consciousness.

e) CCUS technology development.

CCUS is a key technology to reduce CO_2 emission in the mid to long term, and it brings about 31.8% reduction of total CO_2 emissions in 2050 under the DDPP scenario, with an accumulative CO_2 capture of around 27 Gt from 2010 to 2050. However, based on the current status of CCUS technology, it still faces a lot of challenges including unclear national strategies and policies, lack of financing, concern about the integrity of storage, uncertainty of technology innovations, etc. In order to accelerate the implementation of CCUS technologies, it is necessary to strengthen international cooperation with other countries with good experience in developing technologies and lowering costs, accelerate the demonstration project by mobilizing both domestic and international funds, develop a coordinated plan for accelerated development of the technology in the wider possible markets, carry out more research on the integrity of CO_2 storage, and reinforce the education of the public to improve acceptability of these solutions.

6 The change of narrative: From cost to benefit

Traditionally, the climate issue has been closely linked with development in China. Carbon emissions control has long been interpreted as a limit to the development of China's economy, and most of researchers' and decision makers' attention has been focused on the cost associated with carbon emissions reduction. However such old thinking is now changing in China, due to the combined pressure of slowing economic development, more serious energy security concerns, and the challenge of improving air quality. The slowing down of growth makes China interested in new driving forces for its economy. The new energy industry and low-carbon infrastructure is now considered to be an emerging industry that can drive future growth. China has become the top investor in wind turbine, solar PV, nuclear energy, and high-speed railway systems. Those technologies are all linked to a low-carbon transition that may bring more business opportunities for Chinese enterprises. Promotion of a low-carbon transition is no longer regarded as a costly effort, driven mainly by international pressure. Instead, it is considered as an opportunity, a means for propelling China's growth and for avoiding the middle-income trap[16]. The increasing concerns of air quality and energy security are also causing decision makers to hedge those risks by improving energy efficiency and reducing dependence on fossil fuels.

Along with rapid industrialization and urbanization, China is facing serious environmental pollution. Although China has made tremendous efforts to limit air pollution, these measures have not kept up with the growth of its economy and fossil-fuel use. We find that the air pollution in China is closely related to long-term extensive use of coal and other fossil fuel and to the extensive economy growth mode. As China's industrialization, urbanization, and energy consumption continue to increase, pressure to control air pollution also continue to increase. Attributable to stricter control policies in recent years, PM2.5 concentration in 2030 is projected to decrease significantly nationwide, but it is hard for cities in the Yangtze River Delta and the Beijing-Tianjin-Hebei region to meet compliance requirements. Advanced end-of-pipe control measures are available to achieve acceptable levels of air quality, but some key cities need to restructure their energy and industry sectors in order to better comply with control policies. Therefore, accelerated transformation of its economic development mode and energy structure is of great significance for China's future clean air.

The thinking in China about climate action has changed. Addressing climate change is no longer seen as a threat to development but rather as an opportunity for better growth. However, it is unclear how China can achieve a low carbon transition. China has been transitioning to a market economy, but still has many regulations. The challenge faced by the Chinese government in the future will be how to make the market play a constructive role in bringing about a low-carbon transition, reducing the need for command-and-control regulation. This calls for the elaboration of a complex policy package, able to articulate different types of policy instruments to trigger the most efficient way the low-carbon transformations in all aspects of the Chinese socio-economic system.

Under a peak carbon emissions and coal consumption scenario, with integrated measures of structural adjustment and advanced end-of-pipe

16 This describes a situation where in a country stagnate after reaching middle income status (5000-10000$ per capita) but don't go to the level of advanced countries..

control, air-quality modelling results show that air quality in China's major cities could meet national Grade II standards by 2030. With further optimization of energy and industrial structure on the basis of the End-Of-Pipe scenario, SO2, NOx, PM2.5, VOC and NH3 emissions will decrease by 78%, 77%, 79%, 52%, and 42%, respectively, from 2010 levels.

Under the DDPP scenario, compared with existing policies and measures, various measures for further energy-saving will be taken, including changes in the mode of economic development, changes of lifestyle, energy structure adjustment, and incentives for the application of advanced technologies. With optimization of the economic structure, the emerging[17] and tertiary industries will develop rapidly, and advanced technologies will be widely used to save energy. The DDPP scenario demonstrates the feasibility of many transformations, compared to the Business As Usual scenario, aligning the low-carbon objective with development priorities, including i) lower total energy demand, ii) improvements to the energy structure, iii) a cap in coal consumption and a reduction of the share of coal in energy consumption to nearly 50% in 2030, with coal use concentrated in the electricity and heating sectors with advanced end-of-pipe control and limitation of coal use in small facilities, iv) a rise of the share of natural gas and non-fossil fuel to more than 35%, notably through prioritization of natural gas in the residential sector or as a substitute to coal, v) a curbing of the production in energy-intensive industries, confining to mainly to domestic demand, with a peak of production of energy-intensive products near 2020 (notably the production of steel and cement in 2030 is estimated to be lower than 2010), vi) improved energy efficiency, in line with the advanced standards of developed countries, making industrial production more efficient and more clean, vii) energy-saving standards in new buildings and for public consumption .

7 Policy recommendation

Promote the transition from carbon intensity control to total carbon emissions control gradually. As China has set the goal of peaking around 2030, setting carbon-intensity reduction targets for each year and for every five years is inadequate for controlling carbon emission as the economy continues to grow. A transition to total carbon emissions control is necessary in order to realize absolute carbon emissions reduction. In the short- and medium term, when the focus is on reversing the rapid increase in carbon emissions by 2020, it would be useful to set mandatory national carbon emissions standards for key products, industries, and sectors to pilot carbon emissions control in these areas. Meanwhile, aiming at peaking around 2030, it will be necessary to establish an allocation of allowance management system in order to set up the total carbon emissions control scheme by2030, and the allowance of each province, autonomous region, and municipality must be determined accordingly. In the long term, focused on achieving a steady decrease of carbon emissions before 2050, an economy-wide total-carbon-emission-control regulatory system and implementing scheme must be established.

17 Including advanced equipment industry, information industry, biomedical industry, aviation industry, new material industry, new energy industry and energy saving and environmental friendly industry.

Rely more on market-based measures by developing a reasonable pricing system based on GHG emissions. Market-based mechanisms can be more effective than administrative measures in reducing GHG emissions and lowering emissions-reduction costs in some sectors, and are positioned as important measures in some sectors in EU's GHG emissions-reduction strategy. Considering China's process of marketization, it is necessary to build a national carbon market during the 13th Five-Year Period, based on current carbon cap-and-trade pilots; to establish detailed and effective regulations of enforcement; and to continue to improve it afterwards. The population, GDP, and total energy consumption in these seven pilots are 18%, 27%, and 23% of that of China respectively in 2010, covering more than 20 industries and with total allowances of 1.2GtCO_2 per year. In order to realize the transformation from pilots to a national carbon market, a series of national administrative measures and rules should be launched and national allowance allocation method should be developed. In parallel, the optimization of policy designs will have to be continued, notably through the use of fiscal subsidies and pollutant discharge fees. In light of sources of pollution that are difficult to regulate with a carbon market, such as private vehicles existing fossil fuel subsidies, such as the oil consumption subsidy, should be gradually eliminated, and a sectorial carbon tax mechanism should be established to realize GHG reduction for these sources. Along with modernization of energy production and consumption, it is necessary for government to extend energy system reforms, especially electricity market reform, so as to let the market play the dominant role in resource allocation and build an energy-pricing system that reflects the environmental costs of their externalities, which is also crucial for the effective and efficient implementation of a carbon market in China.

Strengthen capacity building in statistical and accounting systems and improve assessment and appraisal systems. Lacking consistency in energy statistical data on the national, provincial, and sectorial level has been a major barrier in setting reasonable but ambitious emissions control targets. In 2014, China set up a statistical indicator system for addressing climate change and a statistics-reporting system for climate change departments. It is highly recommended that China accelerates the establishment of comprehensive guidance on data sources and methodologies on both the provincial and sectorial levels (especially for key industries) before 2020, and enhance its MRV system on the basis of existed MRV guidelines issued by National Development and Reform Commission of China. In the long-term perspective, it is essential to assess the performance of emissions-reduction policies and measures with an appropriate performance appraisal system, so as to clearly follow the efforts in adjusting the industrial structure, saving energy, and optimizing the energy resource mix in order to successfully achieve goals for emissions reduction on the national, provincial and sectorial levels.

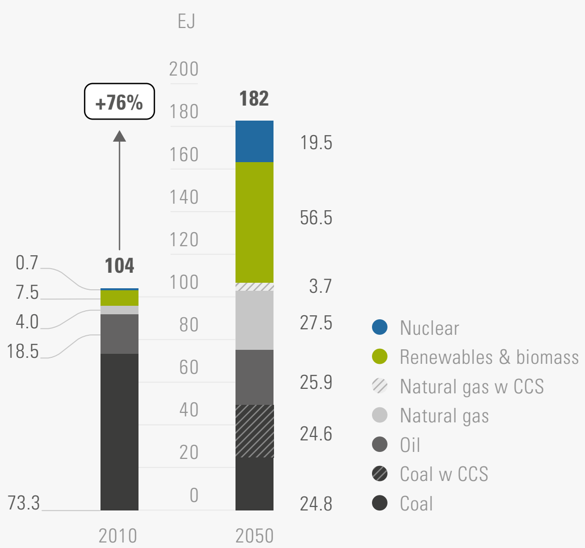
Advocate low-carbon consumption and promote broad participation by the public. As China concludes its process of industrialization around 2020, urbanization will be the main driving force of energy consumption and GHG growth in the long run while the living standard continues to improve. Therefore, it's highly important to promote a low-carbon-consumption lifestyle throughout the whole society. By gaining experience and learning lessons from all kinds of low-carbon-consumption pilots by 2020, the low-carbon consumption concept should be promoted through multiple channels and the media. To promote GHG-related information disclosure and low-carbon goods and services supply, a carbon disclosure mechanism should be established that enforces compulsory carbon labels and carbon footprint information on key products and sectors, followed by a gradual extension to all sectors. In addition, dedicated investments in low-carbon infrastructure and services should be expanded to provide adequate infrastructural context for low-carbon development, e.g., by developing public recreational facilities, optimizing slow-traffic systems, and traffic transfer systems. Emphasizing a low-carbon operation and management mode after 2030, smart and low-carbon communities should be developed through information-based processes, such as Internet of Things and the intelligent house, and low-carbon property management should be promoted through the use of electronic and intelligent service platforms. Furthermore, the economy incentives should be strengthened to promote the low-carbon consumption, such as the adoption of low-carbon-oriented energy-pricing mechanism and carbon tax.

Standardized DDPP graphics for China scenarios

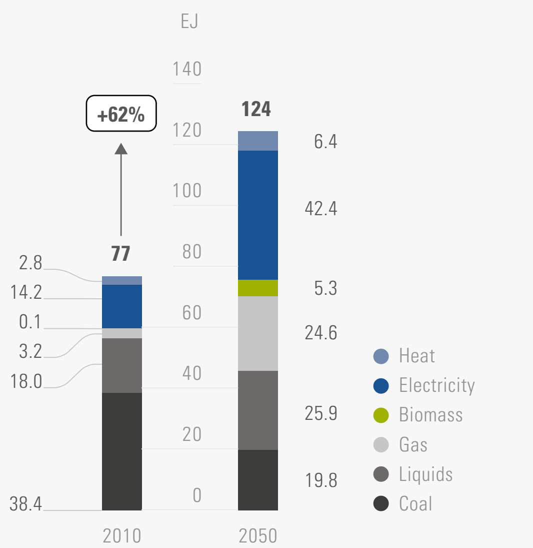
CN – Central Scenarios
CN – High EV
CN – Low CCS

CN – Central Scenarios

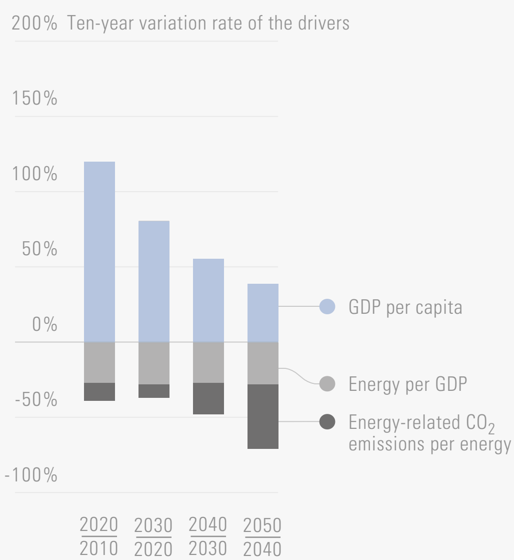
Energy Pathways, Primary Energy by Source



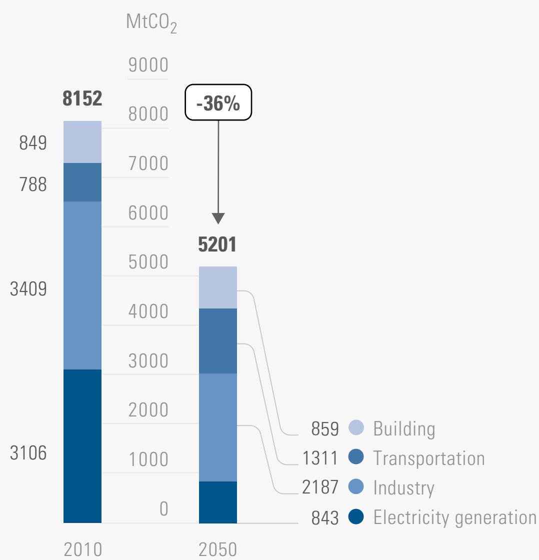
Energy Pathways, Final Energy by Source



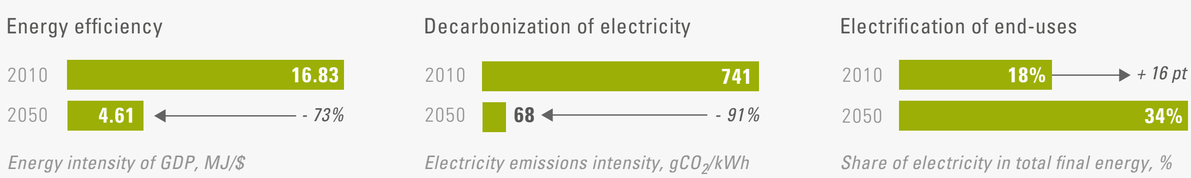
Energy-related CO_2 Emissions Drivers, 2010 to 2050



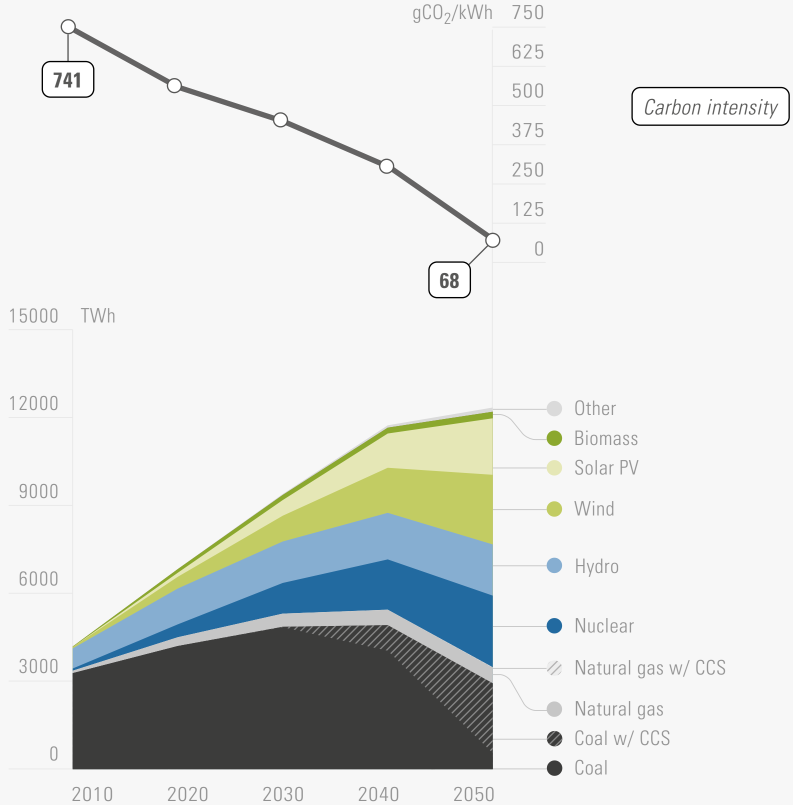
Energy-related CO_2 Emissions Pathway, by Sector



The Pillars of Decarbonization

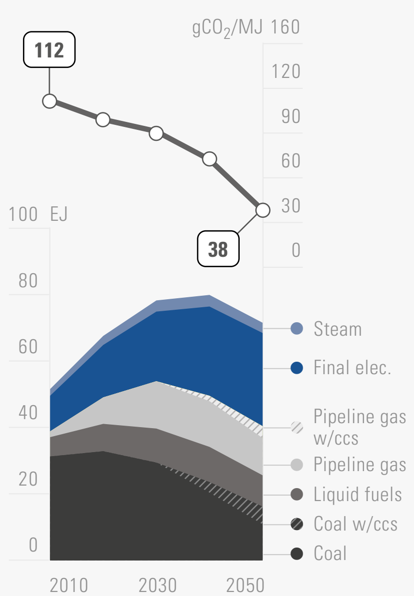


Energy Supply Pathways, by Resource

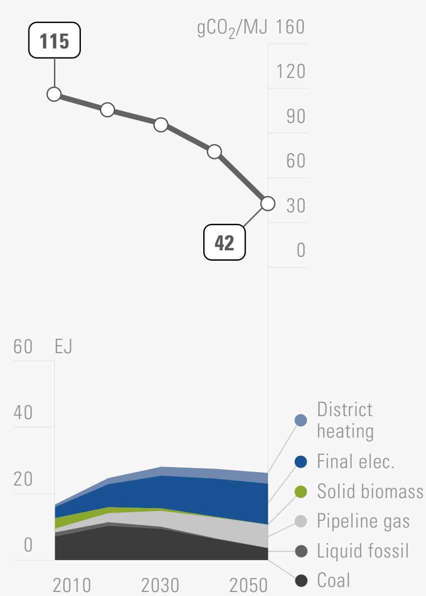


Electricity

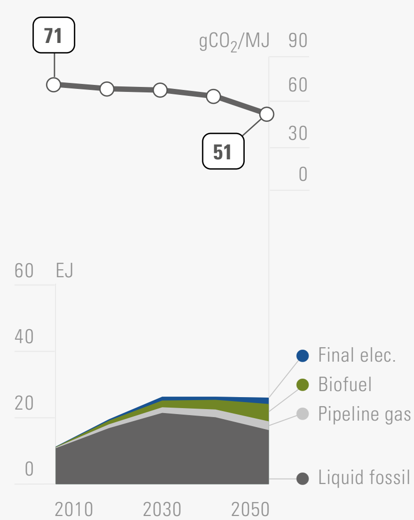
Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050



Industry



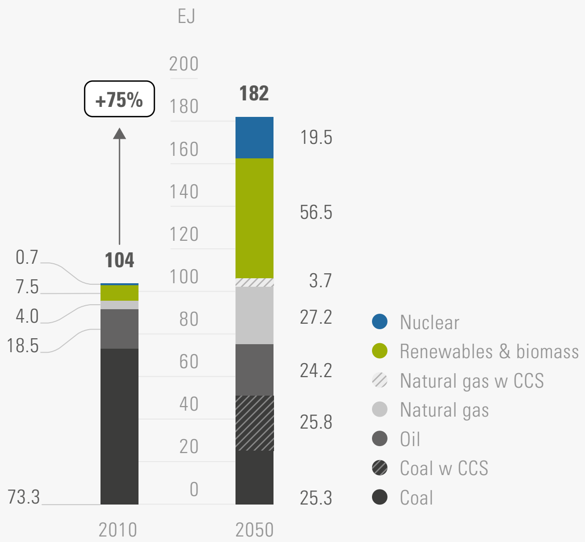
Buildings



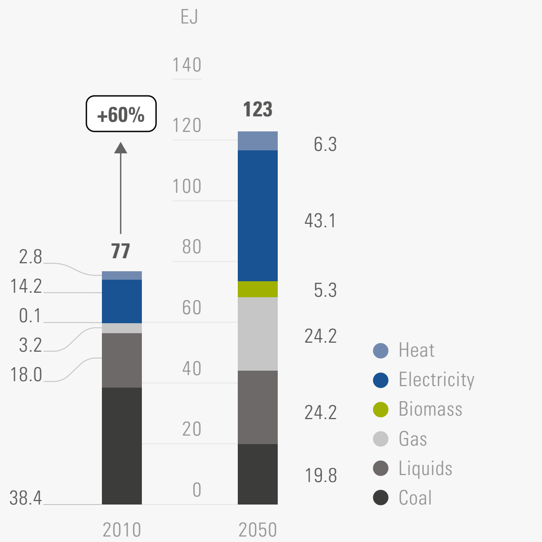
Transportation

CN – High EV

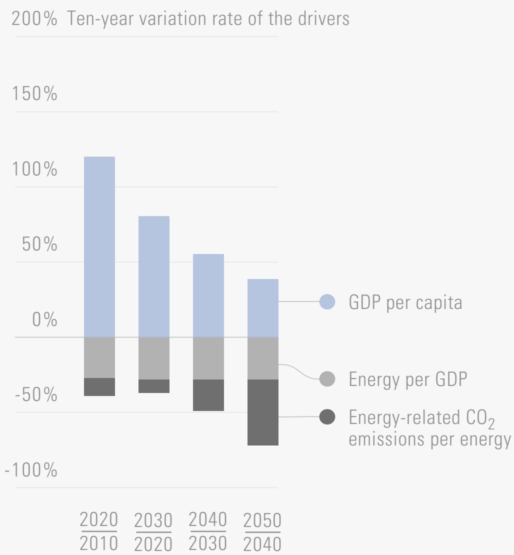
Energy Pathways, Primary Energy by Source



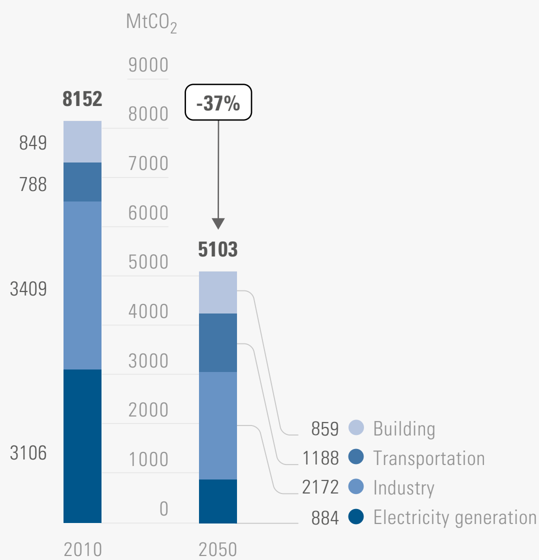
Energy Pathways, Final Energy by Source



Energy-related CO_2 Emissions Drivers, 2010 to 2050



Energy-related CO_2 Emissions Pathway, by Sector



The Pillars of Decarbonization

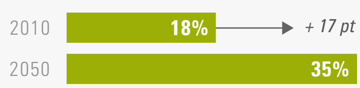
Energy efficiency

Energy intensity of GDP, MJ/$

Decarbonization of electricity

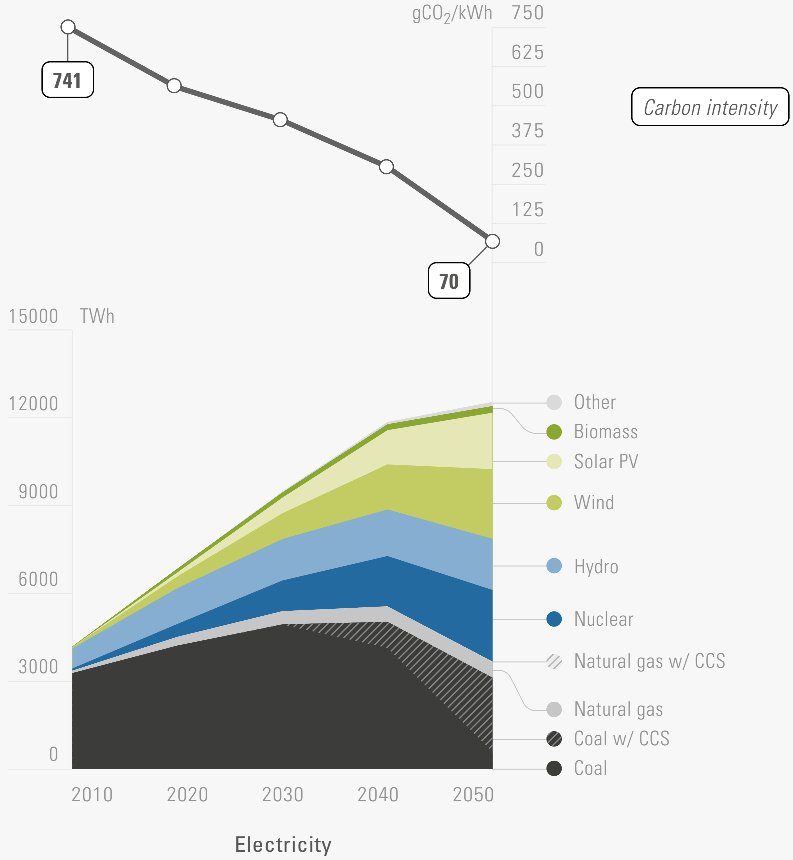
Electricity emissions intensity, gCO_2/kWh

Electrification of end-uses

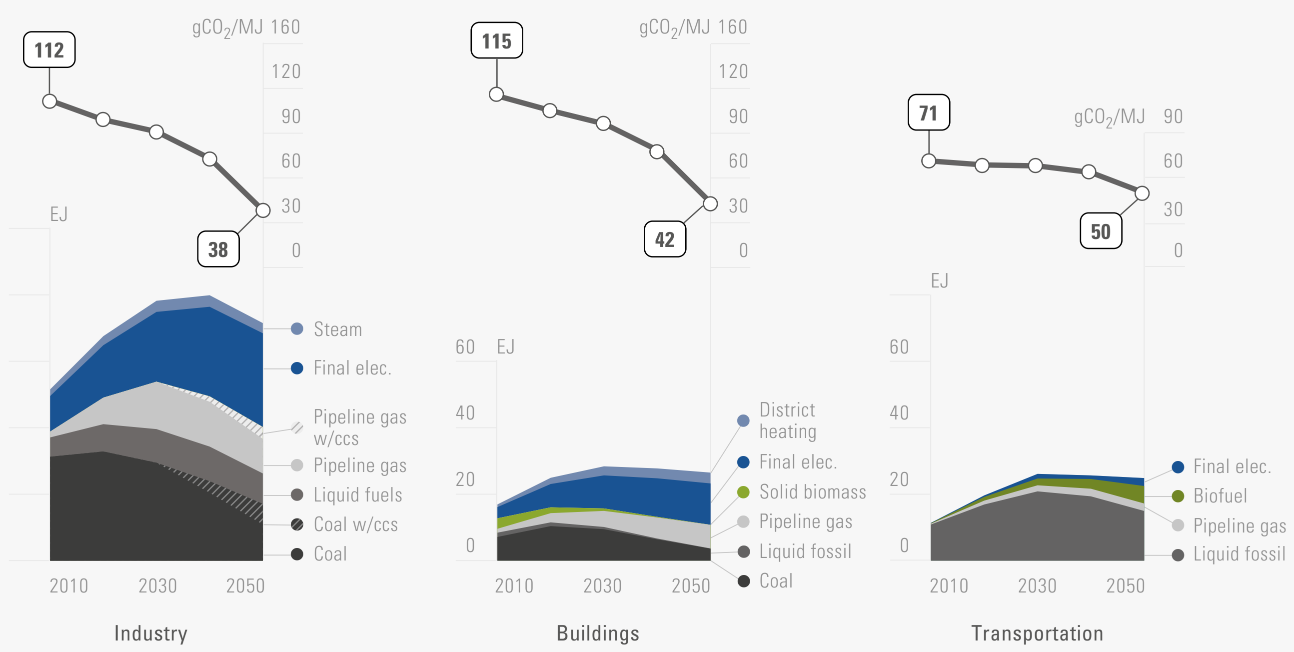


Share of electricity in total final energy, %

Energy Supply Pathways, by Resource

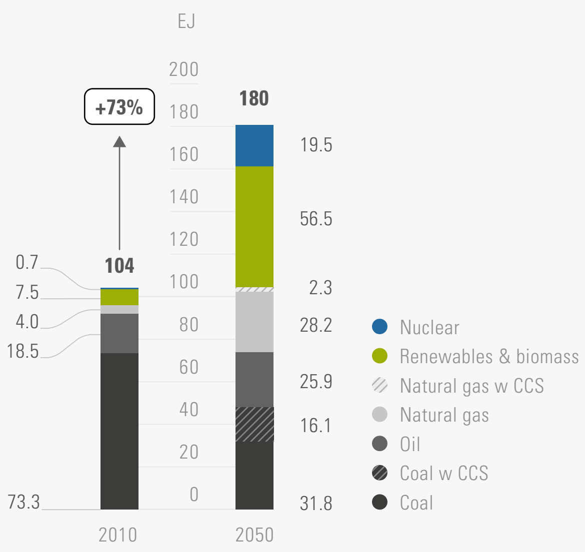


Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050

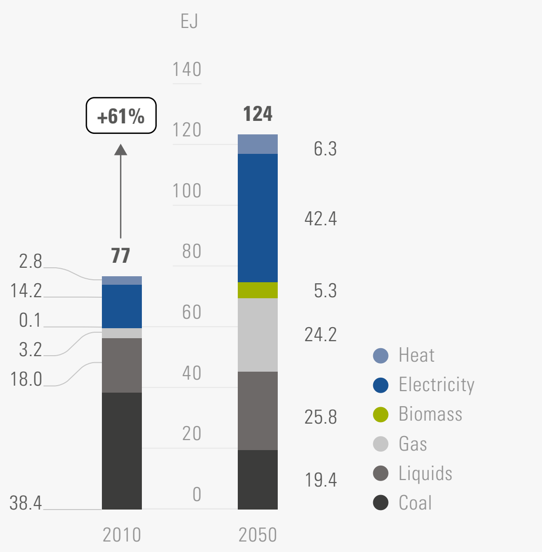


CN – Low CCS

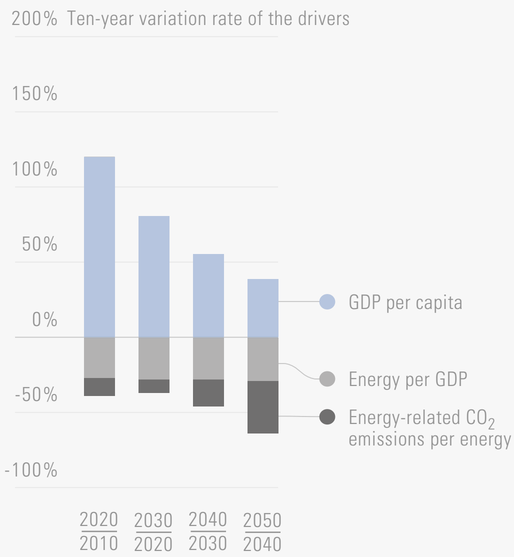
Energy Pathways, Primary Energy by Source



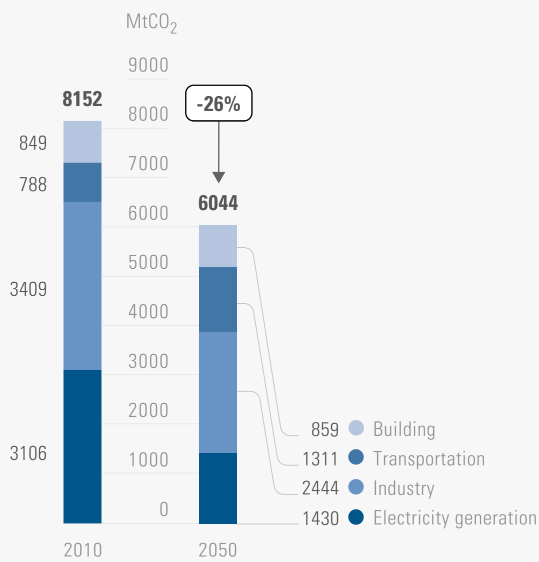
Energy Pathways, Final Energy by Source



Energy-related CO_2 Emissions Drivers, 2010 to 2050



Energy-related CO_2 Emissions Pathway, by Sector



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Energy intensity of GDP, MJ/$

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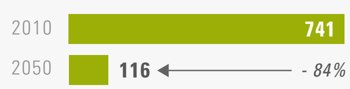
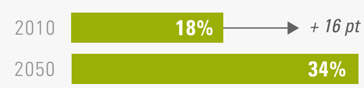


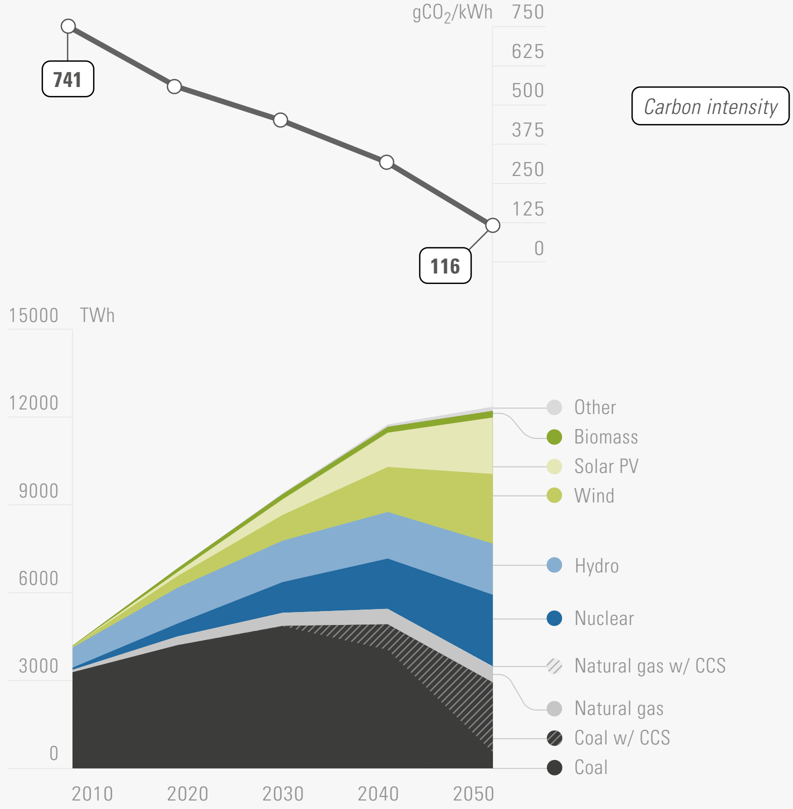
Electricity emissions intensity, gCO_2/kWh

Electrification of end-uses



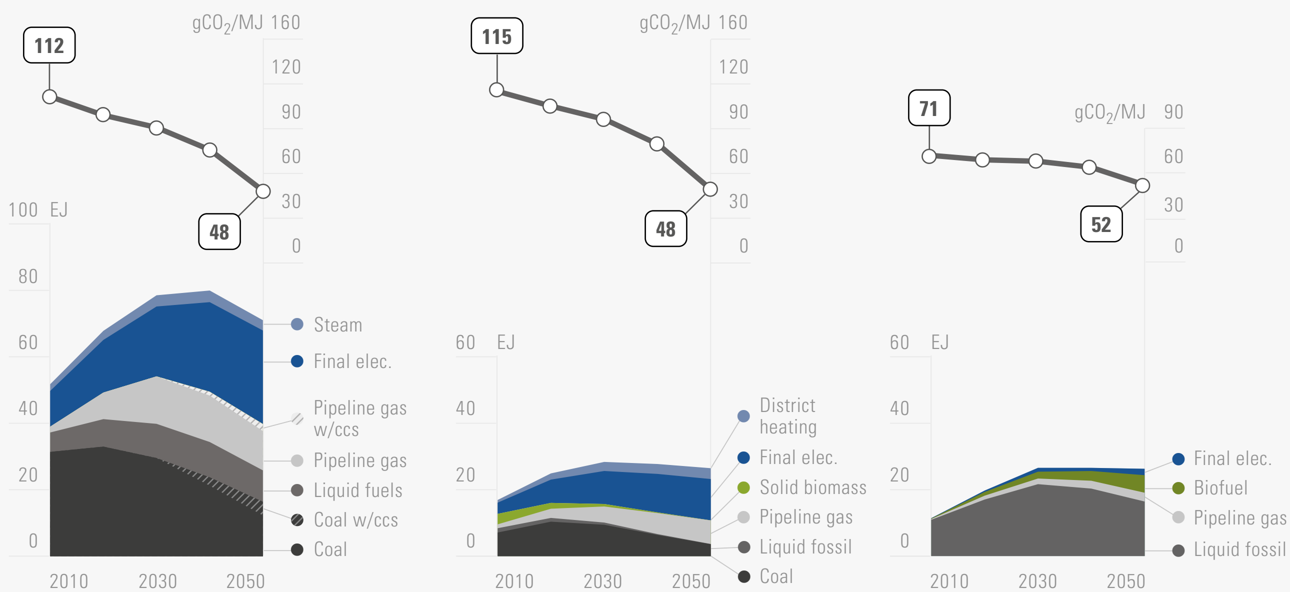
Share of electricity in total final energy, %

Energy Supply Pathways, by Resource



Electricity

Energy Use Pathways for Each Sector, by Fuel, 2010 – 2050



Industry

Buildings

Transportation