Chapter 9
Long-Term Low-Carbon Transition Pathways

The previous chapters provide systematic analysis on the pathways of emissions reduction and the subsequent economic impact under different scenarios in end-use energy consumption sectors, power and energy systems, and non-CO_2 greenhouse gases. In view of the urgency of addressing climate change, it's crucial for China to explore the development pathway of low-carbon transition. In addition, the emission reduction targets and actions should be reinforced to implement the nationally determined contribution commitment by 2030. While, research should be conducted to determine the long-term low-carbon emission targets and approaches suitable for China by 2050. Building on the analysis of previous chapters, we propose to study and propose with recommendations for implementing and updating NDC targets before 2030 under the reinforced policy scenarios. After 2030, further actions should be taken to strengthen the intensity of deep decarbonization, in line with the Paris Agreement target of keeping global temperature rise below 2 °C while pursuing efforts to limit the increase further to 1.5 °C, study and explore the transition pathway to deep decarbonization by 2050.

9.1 Implementing and Reinforcing NDC Targets and Actions for 2030

9.1.1 Energy Consumption and CO_2 Emissions

Since China's economy entered the "new normal" stage, the high quality economic growth has spurred the transition from quantity-driven extensive growth to quality-focused intensive development, industrial structure accelerated in transforming and upgrading, while growth drivers also shifted. Attributed by the actions taken in the 12th Five-Year Plan and roadmap planned in the 13th Five-Year Plan, the share of

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the primary, secondary and tertiary industries in China's GDP improved from 9.3, 46.5 and 44.2% respectively in 2010 to 7.1%, 39.0% and 53.9% respectively in 2019, served to curb the fast growth of energy consumption [1]. In the long run, economic growth is expected to fall back to a medium- to low-growth level. As per the previous analysis and forecast by mainstream domestic research institutions, growth will slide from the current 6% during the 13th Five-Year Plan period to around 4.5–5.0% by 2030.

Among China's current NDC targets, the most important ones involving CO_2 emissions include:(1) CO_2 emissions intensity per unit of GDP to decrease by 60–65% by 2030 from 2005 level; (2) non-fossil energy to account for roughly 20% of the primary energy consumption mix by 2030; (3) CO_2 emissions to peak around 2030 and ideally earlier. These NDC targets were evaluated and proposed before 2015 based on the fulfillment of the goal set out during the Copenhagen Climate Conference in 2009, goals entailed a 40–45% drop in emission intensity by 2020 from 2005 level, and non-fossil energy to account for 15% the primary energy consumption mix. These are also achievable targets in line with China's economic and social reality at that time and in the foreseeable future. *China Statistical Abstract 2020* published China's total primary energy consumption by the end of 2019 is at 4.86 billion tce. The improved energy mix features a further drop of coal in the primary energy consumption mix to 57.7%, non-fossil energy and natural gas increase to 1.0 and 0.3 percent to 15.3% and 8.1% respectively, while oil making up 18.9%, on a par with that in 2018 [2]. By this measure, China has achieved its goals set out in Copenhagen of reducing CO_2 intensity per unit of GDP by 40–45% and for non-fossil energy to account for 15% of primary energy consumption by the end of 2019 ahead of schedule, which laid a solid groundwork to implement and further strengthen the NDC targets.

In 2020, the Covid-19 pandemic plunged global economy into a severe contraction, presenting grave challenges to social stability. At present, it's hard to gauge the exact length and impact from the virus, but it has aggravated global geopolitical issues, sparking a new wave of oil price volatility, and with an unprecedented disruption in global energy market. To reduce the shock of the pandemic on the economy, the world will focus more on economic stimulus to secure social stability in the short-term. And a growing number of scholars have called for "greener" and more "sustainable" economic recovery. With the impact of Covid-19 in mind, this research also adjusted the forecast of China's economic growth amid the recent low-carbon transformation.

According to the *Strategy for Energy Production and Consumption Revolution (2016–2030)* [3] jointly released by National Development and Reform Commission and National Energy Administration, power generation from non-fossil energy will reach approximately 50% of total electricity use by 2030. Study in the report also finds that over 50% of primary energy will be used for electricity production by 2030, which means that non-fossil energy is on track to comprise of roughly 25% of primary energy consumption by 2030 with increasing electrification in the future [4]. With China's attention shifting to low-carbon transformation of the energy mix, non-fossil energy has gained some weight in primary energy consumption, but it still falls short of developed countries. In the short term, newly added non-fossil fuels can't adequately meet the needs of total additional energy demand with decarbonization efforts. Natural gas, as a "relatively low carbon" "clean" energy option, will grow in importance, serving as a "transition" toward a non-fossil centered energy mix.

By 2030, coal, oil, natural gas, and non-fossil energy as a percentage of China's primary energy consumption will be improved to 45%, 17%, 13%, and 25% respectively from 57.7%, 18.9%, 8.1% and 15.3% respectively in 2019. Among them, the share of non-fossil fuels will rise by another five percent compared with the current NDC target of 20%, and coal-use can be further reduced through enlarging the size of natural gas in primary energy consumption. By enhancing the energy mix, CO_2 intensity per unit of energy consumption will drop from 2.085 $kgCO_2$/ kgce to 1.75 $kgCO_2$ / kgce, down 16%, paving the way for further reduction in CO_2 intensity per unit of GDP.

The Covid-19 puts a brake on the economic growth in 2020, triggering a slowdown of the annual GDP growth to 5.7% during the 13th Five-Year Plan period. Based on the current progress of recovery, the annual GDP growth is expected to be above 5% in the 14th Five-Year Plan period (see Table 9.1). This new period features the implementation of a new development philosophy which will steer new sources of economic growth and new infrastructure investment towards the digital economy and high-end technology sectors, with the saturation or reduction in the demand for energy intensive raw materials and products such as steel and cement and a reduced elasticity in energy consumption. Energy consumption per unit of GDP will experience a decline equivalent to that in the 13th Five-Year Plan period, or no less

Table 9.1 Energy consumption under the enhanced NDC target and its CO_2 emissions

		2005	2010	2015	2020	2025	2030
Annual GDP growth rate (%)			11.3	7.9	5.9	5.3	4.8
5-year decline in energy consumption per unit of GDP (%)			19.1	18.5	14.3	14.0	14.0
Energy consumption (billion tce)		2.61	3.61	4.34	4.94	5.50	5.98
Energy consumption structure	Coal (%)	72.4	69.2	63.7	57.0	51.0	45.0
	Oil (%)	17.8	17.4	18.3	18.5	18.0	17.0
	Natural gas (%)	2.4	4	5.9	8.5	11.0	13.0
	Non-fossil fuel (%)	7.4	9.4	12.1	16.0	20.0	25.0
CO_2 emissions per unit of energy consumption ($kgCO_2$ / kgce)		2.32	2.25	2.16	2.03	1.90	1.75
CO_2 emissions ($GtCO_2$)		6.06	8.13	9.37	10.03	10.45	10.46
5-year decline in CO_2 emissions per unit of GDP (%)			21.5	21.2	19.7	19.5	20.6
Decline from the 2005 level (%)					50.3	60.0	68.2

than 14%. Total energy consumption could reach 5.5 billion tce and 5.98 billion tce by 2025 and 2030 respectively. Given the economic growth prospect in this study, with the prediction of total energy consumption and energy mix, CO_2 emissions in 2030 will reach a total of 10.46 billion tCO_2, with CO_2 intensity per unit of GDP falling by 68.2% from 2005 level, surpassing the upper limit of the 60–65% reduction in China's NDC target. CO_2 emissions will reach a plateau around 2025 and hit the peak before 2030. Table 9.1 illustrates energy consumption and CO_2 emission levels before 2030 with intensive energy conservation and carbon reduction policies and measures, which will fully exceed the 2030 NDC target.

9.1.2 Policies and Measures for Enhanced NDC Targets and Actions

As required by the Paris Agreement, countries should report and update their NDC targets by the end of 2020. This includes not only the emission reduction targets of each party, but also the goals and actions of enforcing the strategic measures and policies on this front, which encapsulates the actions to fully implement the national strategy on climate change. Given the achievements and strides China has made in this regard, the following key considerations can be made to strengthen the 2030 NDC targets and efforts:

1. Strive to exceed the 2030 NDC targets. With non-fossil energy getting momentum in recent years, its share in primary energy consumption is expected to climb from 20 to 25% in 2030. A low-carbon energy system will facilitate a further reduction of China's CO_2 intensity of GDP. Through the current efforts, progress and active preparations in the 14th and 15th Five-Year Plan periods, China is on track to cut its CO_2 intensity of GDP by more than 65% around 2030 from the level in 2005, and peak CO_2 emissions before 2030.

2. Put forth guiding goals for curbing total energy consumption and CO_2emissions. A cap on total energy use has been introduced and executed in the 13th Five-Year Plan period, and a similar cap on CO_2 emissions should also be imposed during the 14th Five-Year Plan period to be aligned with the policies and measures to ensure a peak around 2030, which should gradually integrate or replace the cap on total energy consumption. The cap on emissions should not put a ceiling on energy consumption of local governments and enterprises. Rather, it should encourage them to tap into new and renewable sources of energy in a bid to propel a revolution in energy production and consumption. The cap could also be aligned with the ongoing efforts to establish national carbon market to gradually move from the right to energy use system toward the enterprise carbon allowance system, demonstrating China's reinforced efforts in climate change.

In view of the great uncertainty in future economic development and energy consumption, especially the impact of Covid-19, GDP growth in the 14th Five-Year Plan period still hangs in the balance. Therefore, a relatively looser cap should be adopted to allow some leeway. The total energy consumption should be capped at 5.5 billion tce, total emissions at 10.5 billion tons at the end of 14th Five-Year Plan period, and a CO_2 emission peak before 2030 capped below 11 billion tons. A dual control mechanism with intensity reduction as the mainstay and caps as the supplement should be created, which is also consistent with the characteristics and reality of China's current economic development.

3. Developed areas in the eastern coast of China should peak CO_2emissions earlier. The 13th Five-Year Plan has indicated "support to optimized development areas to secure an earlier CO_2 emission peak". After 2025, China as a whole can enter a peak period of CO_2 emissions. Developed coastal areas in the east are well-positioned to lead in the country, with some cities potentially reaching peak before 2025. Provinces and cities in the southeast region rich in renewable energy can also strive to take the lead for CO_2 emission peak. It's important to develop situational plans for different regions based on local realities, encourage the developed areas in the eastern coast to set out peak targets in order to catalyze the midwest region to transform development patterns. Encourage provinces and cities to create and enforce related targets and policy measures, thereby driving low-carbon economic and social transformation via the CO_2 emissions peak targets.

4. Push for CO_2emission peak before 2025 in energy-intensive heavy chemical industries. Despite a reduced weight in GDP, the industrial sector still represents an mix of energy-intensive industry that consumes more than 60% of the total energy for end-uses in China, making it the most promising sector for energy saving. With adjustment, transformation and upgrading of the industrial structure, the output of heavy and chemical products will be saturated and with potential to decline during the 14th Five-Year Plan period, prompting an earlier peak than transportation and construction, etc. China can make active efforts to set the goal of peaking CO_2 emissions of the heavy and chemical industry sector in the 14th Five-Year Plan, striving for an earlier peak in the entire industrial sector through the leadership of the heavy and chemical industry sector, thus setting the stage for a nationwide peak by 2030.

5. Curtail non-CO_2 greenhouse gases emissions. Non-CO_2 greenhouse gas emissions are mostly short-lived emissions. Despite the diminishing greenhouse impact in their entire lifespan, their complicated sources make for high cost of technologies for emission reduction in the long run, which represent one of the hardest obstacles to overcome for the net-zero emission target in the future. China's current implementation and commitment of NDC mainly focus on energy-related CO_2 emissions, with plenty of room for improvement in the capacity for managing non-CO_2 sources. Thus, the 14th Five-Year Plan period should start to strengthen the management and control of CO_2 and other greenhouse gas emissions from industrial production, agriculture, forestry, waste management, etc., especially for the production and use of fluoride gas, and gradually establish a monitoring, reporting, and verification system for all sources of greenhouse gas emissions, build capacity for the further implementation of mitigation measures and actions, and adapt to the implementation of the Paris Agreement.

6. Deepen the administrative and market-based reform of energy and CO_2emission management system. Now, the burgeoning energy technologies and industrial innovations have sped up the transformation of the energy industry, but some institutional and policy barriers are yet to be overcome. It's essential to advance reform of the energy management and pricing systems, boost the development of distributed renewable energy. Meanwhile, carbon market should be strengthened through prompt efforts in expanding the unified national carbon market to the eight designated energy-intensive sectors, and properly managing carbon allowance in an effort to promote low-carbon transition of the energy and economy with market-based tools during the 14th Five-Year Plan period.

9.2 Analysis of Long-Term Emission Reduction Pathway Driven by the 2 °C Target

Based on previous analysis, more space is needed for carbon emissions and more time is need for low carbon transformation in light of the current economic and social development situation, it is difficult to switch to the 2 °C emission reduction pathway in the near future. To enable long-term 2 °C pathway without sacrificing near-term economic growth, a feasible option is to step up emission reduction efforts based on the reinforced policy scenario before 2030, laying solid groundwork for the transition toward the 2 °C. In addition, achieve carbon peak before 2030, with additional emission reduction efforts and use the goal of staying within 2 °C by 2050 to force the leap toward the 2 °C target. This section builds the feasible long-term low-carbon transition scenario based on enhancing NDC targets before 2030 elaborated in Sect. 9.1, and facilitating greater emission reduction in the entire economy and society toward the 2 °C scenario after 2030.

9.2.1 Comprehensive Analysis of the 2 °C Target Path Scenario

The Paris Agreement sets its long-term temperature goal to hold global average temperature increase "well-below to 2 °C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels". Under the guidance of "the two-step strategy of new era", China should also undertake its mitigation efforts and contributions in combating climate change in accordance with its development toward a great, modern socialist country. In this context, China's domestic long-term strategy of low-carbon development should be in line with the long-term goal of the Paris Agreement by limiting the temperature rise to well below 2 °C [5]. Based on the analysis of the reinforced policy scenario and the 2 °C scenario in the previous sections, the emission reductions pathway can be gradually

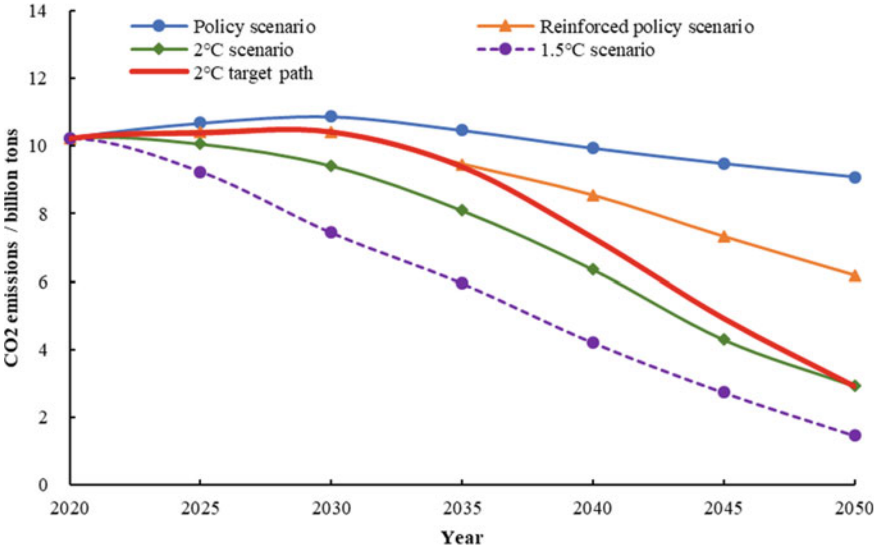


Fig. 9.1 CO_2 emissions in different scenarios and the 2 °C target path

achieved in two stages as China embraces high-quality economic transition: before 2030 (Stage one), before 2030, we should strive for emission reduction actions that are more ambitious than the enhanced NDC targets based on the reinforced policy scenario in order to peak carbon emissions earlier, whch makes it highly likely to transit toward the 2 °C scenario at the same time; after 2030 (stage two), the priority should be given to the low-carbon energy system and improved energy efficiency to speed up the transition toward the 2 °C target, thus achieving the goal of emission reduction effectively under the 2 °C scenario by 2050. Accordingly, this section provides the 2 °C target oriented transition scenario pathway (2 °C target path shown in Fig. 9.1). The data of economic growth, energy mix assumptions, and energy-related CO_2 emissions in major years are illustrated in Table 9.2.

Before 2030, the enhanced NDC plan proposed in Sect. 9.1 should be adopted to support the expected economic and social growth with a lower carbon-intensity energy mix. In the meantime, steps should be taken to boost technological efficiency and cut back emissions, further reduce energy consumption elasticity while optimizing industrial structure, actively pursue more ambitious emission reduction before 2030 than the enhanced NDC targets, laying the foundation for the transition to 2 °C pathway after 2030. Energy-related CO_2 emissions can be brought down to 10.46 billion tons by 2030, which signifies the start of a downward trend after peak before 2030. From 2030 to 2050, a lower carbon-intensity energy mix can be achieved with the share of non-fossil energy in primary energy consumption increasing from 25% in 2030 to 73.2% in 2050, and the share of coal, oil, and natural gas decreasing from 45%, 17%, and 13% in 2030 to 9.1%, 7.7%, and 10.0% in 2050 respectively (see Fig. 9.2). The new energy system with non-fossil fuels as the mainstay would by

Table 9.2 Economic growth, energy consumption and CO_2 emissions in the 2 °C target path

Item (unit)		2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Annual GDP growth rate (%)		-	11.3	7.9	5.9	5.3	4.8	4.4	4.0	3.6	3.2
GDP index (2005 = 1)		1	1.71	2.50	3.33	4.31	5.45	6.75	8.22	9.81	11.48
Energy consumption (billion tce)		2.61	3.61	4.34	4.94	5.50	5.98	6.06	5.89	5.58	5.20
Energy consumption structure	Coal (%)	72.4	69.2	64	57	51	45	36	28	19	9.1
	Oil (%)	17.8	17.4	18.1	18.5	18	17	17	13	9	7.7
	Natural gas (%)	2.4	4	5.9	8.5	11	13	15	14	12	10
	Non-fossil fuel (%)	7.4	9.4	12	16	20	25	32	45	60	73.2
CO_2 emissions per unit of energy consumption ($kgCO_2$/kgce)		2.32	2.25	2.16	2.03	1.90	1.75	1.55	1.24	0.88	0.56
Annual decline in CO_2 emissions per unit of energy consumption (%)		-	0.58	0.83	1.27	1.30	1.59	2.46	4.38	6.50	8.62
CO_2 emissions (Gt CO_2)		6.06	8.13	9.38	10.03	10.45	10.46	9.38	7.29	4.93	2.92
Annual decline in energy consumption per unit of GDP (%)		-	4.15	3.82	3.09	2.97	2.97	3.96	4.39	4.53	4.44
Annual decline of CO_2 emissions per unit of GDP (%)		-	4.72	4.62	4.33	4.23	4.57	6.32	8.58	10.74	12.74
Decline from the 2005 level (%)		-	21.5	38.0	50.3	60.0	68.3	77.1	85.4	91.7	95.8

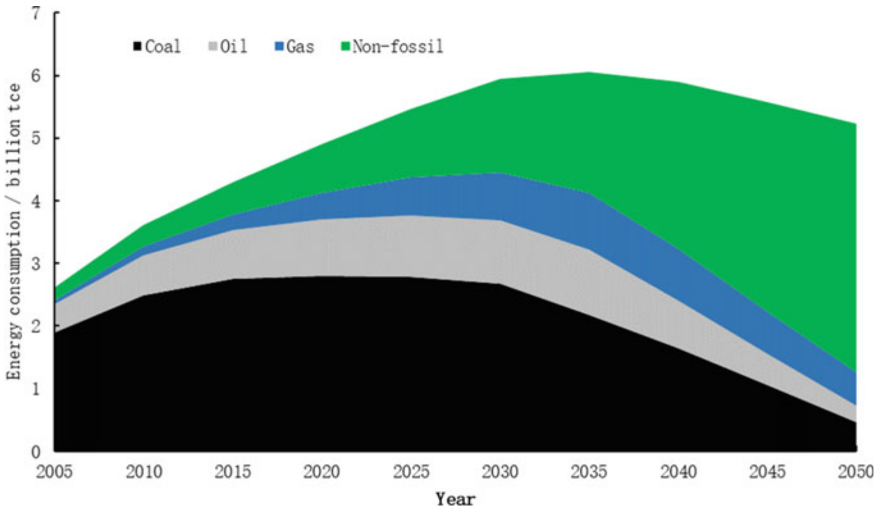


Fig. 9.2 Primary energy consumption and its mix in the 2 °C target path

then provide major buttress to the economic and social development, with increasing decoupling of economic growth and energy consumption. By 2050, energy-related CO_2 emissions can be reduced to 2.92 billion tons. Considering CO_2 emissions from industrial process, carbon sink, and CCS, the net CO_2 emissions would be 2.18 billion tons with a per capita CO_2 emission of about 1.5 tons, which is lower than the world's per capita level under the 2 °C target path, paving the way for the prompt achievement of net-zero emission after the middle of this century. Table 9.3 shows the sectoral breakdown of energy consumption and CO_2 emissions under 2 °C target path.

Between 2030 and 2050, direct CO_2 emissions from the industrial and electricity sector remain the largest contributor to energy-related CO_2 emissions. In 2050, the direct CO_2 emissions from the electricity sector (the carbon sink from CCS not

Table 9.3 Energy consumption and CO_2 emissions by sector in the 2 °C target path

	2020		2030		2050	
End users	Energy consumption (billion tce)	Emissions ($GtCO_2$)	Energy consumption (billion tce)	Emissions ($GtCO_2$)	Energy consumption (billion tce)	Emissions ($GtCO_2$)
Industrial	1.61	3.77	1.88	4.15	0.69	1.19
Building	0.55	1.00	0.51	0.88	0.26	0.31
Transport	0.49	0.99	0.54	1.09	0.30	0.55
Power	2.17	4.06	2.83	3.95	3.92	0.83
Other sectors	0.12	0.21	0.22	0.38	0.03	0.04
Total	4.94	10.03	5.98	10.46	5.20	2.92

Table 9.4 Total CO_2 emissions and their composition in the 2 °C target path (unit: $GtCO_2e$)

	2020	2030	2050
CO_2 emissions from energy consumption	10.03	10.46	2.92
CO_2 emissions from industrial production	1.32	0.94	0.47
CCS/BECCS	0.00	0.00	-0.51
Forest carbon sinks	-0.58	-0.61	-0.70
Net emissions	10.77	10.79	2.18

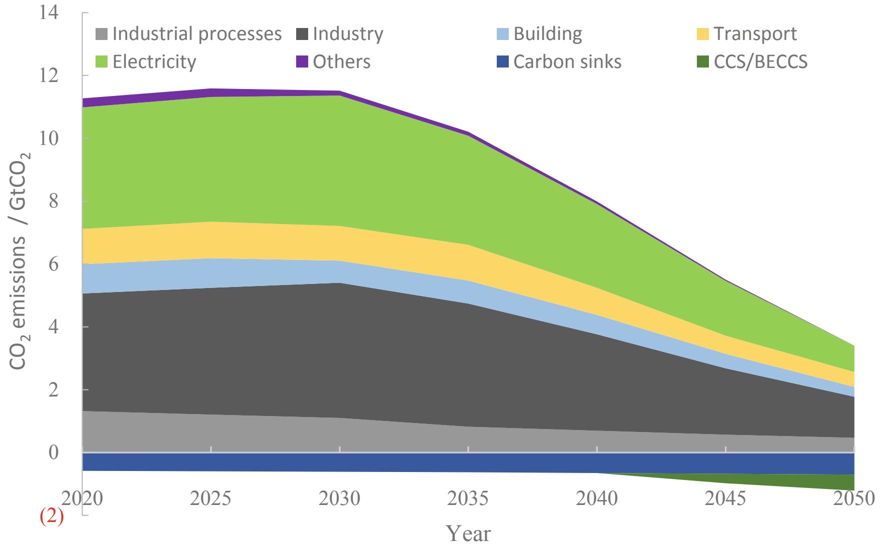


Fig. 9.3 CO_2 emissions by sector in the 2 °C target path

included), driven by a lower carbon energy mix, are down by roughly 80% from the 2020 level, providing low-carbon power to the end users. CO_2 directly emitted from energy consumption stands at 2.92 billion tons, and emissions from industrial processes are about 470 million tons, the size of forest carbon sinks and CCS will reach 700 million tons and 510 million tons respectively in 2050. The total net CO_2 emissions in 2050 reach 2.18 billion tons, about a 80% decrease from the peak year. The total CO_2 emissions under 2 °C target path are shown in Table 9.4 and Fig. 9.3.

9.2.2 Pathway Analysis of the 2 °C Target Path Scenario

By comparing the CO_2 emission trajectories of the 2 °C target path and the four emission reduction scenarios mentioned earlier (see Fig. 9.1), the results show that

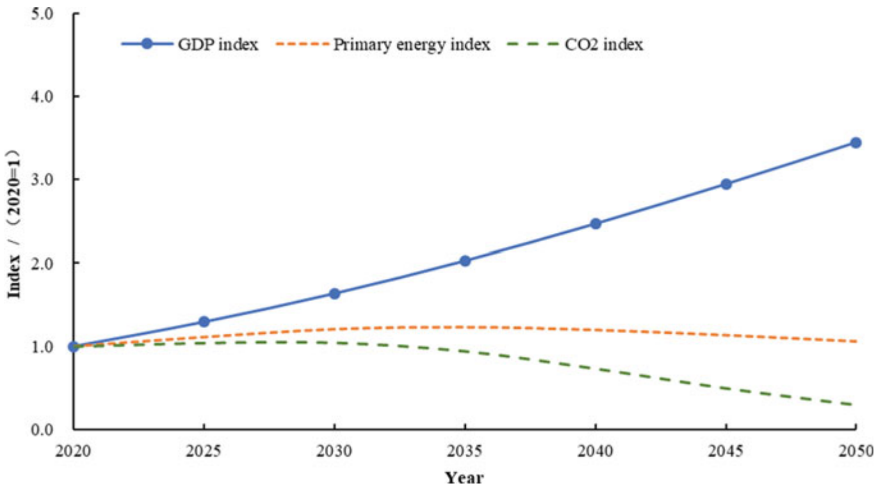


Fig. 9.4 Indexes of GDP, primary energy consumption, and CO_2 emissions (2020 = 1)

the 2 °C target path is somewhere between the reinforced policy scenario and the 2 °C scenario, in line with China's current development stage and characteristics. That is, before 2030, to ensure a smooth transition of the economy and society still require certain space of carbon emissions, but the low-carbonization process of the energy structure is expected to be further strengthened; after 2030, the entire economy and society will experience a rapid transition, and meet the 2 °C scenario by 2050.

In the 2° C target path scenario, by 2050, the total GDP is 3.5 times larger than that of 2020. After peaking around 2035, the total energy consumption gradually falls, but new and renewable energy continue to develop rapidly. CO_2 intensity per unit of energy consumption spirals down. As CO_2 emissions and GDP growth are decoupled before 2030, the decrease of CO_2 emissions per unit of GDP after 2030 will reach to 10% annually after 2040 (see Figs. 9.4–9.6). The change in energy mix provides increasingly greater contributions as time goes on.

The year-by-year trend of energy conservation and energy substitution in the reduction of CO_2 intensity in GDP under the 2 °C target path are showed in Fig. 9.5. Without considering the second-order infinite quantity [6], the annual decline of CO_2 intensity of GDP can be approximately expressed as the sum of the annual drop of energy intensity of GDP (or referred to as the energy-saving effect) and the annual decrease in CO_2 intensity of energy consumption (or referred to as the energy substitution effect). Data in the figure suggests that after 2030, with the swift transition to the 2 °C target, CO_2 intensity of GDP sees faster annual decline from 4.5% between 2025 and 2030 to 12.7% between 2045 and 2050. With the rapid advancement of low-carbon energy mix, non-fossil energy gradually replaces coal to become the mainstay in primary energy composition, making greater contribution to carbon reduction. With the spread of energy-saving technologies, the future energy intensity of GDP is likely to maintain an annual fall of 4–5%. This signifies that after

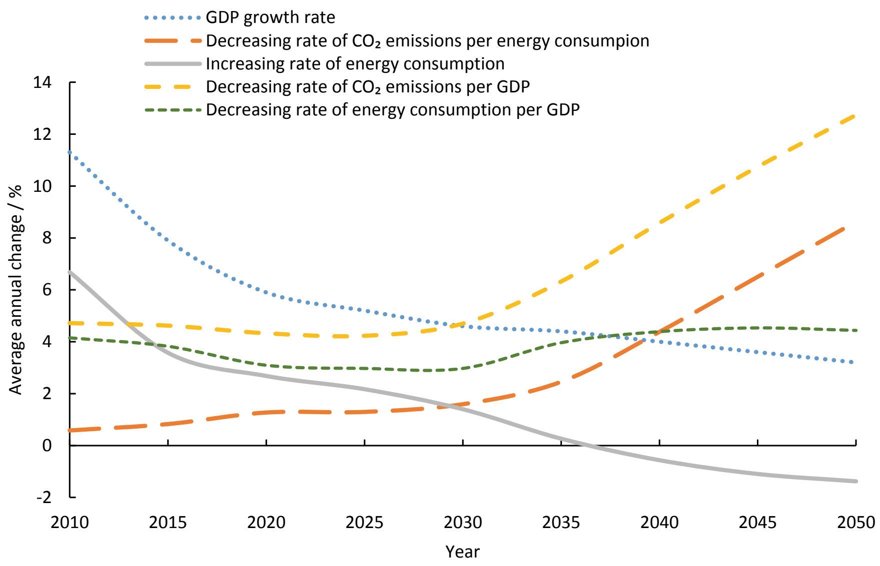


Fig. 9.5 Analysis on the decline of GDP growth and CO_2 emissions per unit of GDP

2040, energy substitution is set to be a greater contributor to the reduction of CO_2 intensity of GDP than energy conservation.

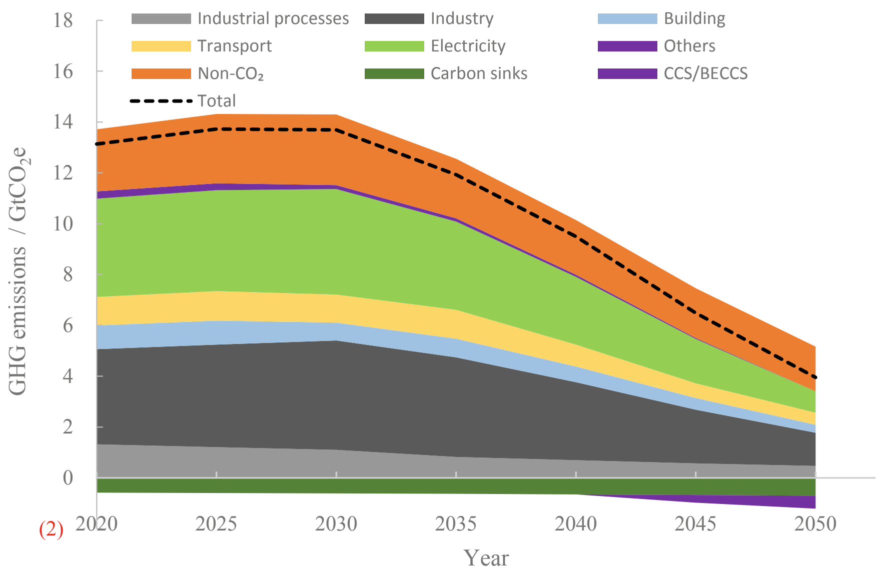


Fig. 9.6 Greenhouse gas emissions under the 2 °C target path

Two curves representing the expected GDP growth and the deceasing rate of CO_2 emissions per capita GDP meets at point A, the year when the CO_2 emissions peak occurs. Point B is the focal point of the annual growth rate of energy consumption and the annual rate of decline of CO_2 intensity of energy consumption. It suggests that the annual CO_2 intensity in energy consumption is declining at a greater rate than the annual growth rate of energy consumption, which also signals the CO_2 peak from an energy point of view. Point C represents the year with zero annual growth of energy consumption when economic growth is officially decoupled from energy consumption, that is, economic growth can be achieved without using additional energy—a new stage of endogenous growth. Data in the chart shows that economic growth is on track to decouple from energy consumption in the period from 2035 to 2040 under the 2 °C target path. Energy savings from technological progress and profound economic restructuring can meet the energy demand of economic growth. Overall, it shows a continuous downward trend of total energy consumption amid economic growth.

Compared with the policy scenario, the 2 °C target path is characterized by dramatic emission reduction in end users and the power sector, shown in Table 9.5.

Compared with the policy scenario, the 2 °C target path enables a 76.7% reduction in emissions by 2050, with the biggest contributors being the industrial sector and power sector (34.7% and 34.2% respectively) and CCS contributing 7.1% to as well.

9.2.3 Result of the 2 °C Target Path Through Different Statistical Methods

In measuring renewable energy consumption, this report converts the power generated from renewables as hydro, wind, and solar into primary energy based on coal equivalent calculation method, which is China's traditional statistical methodology. Some other countries and international agencies (e.g.: the IEA) do so based on the method of calorific value calculation. In the case of around 40% efficiency of traditional fossil energy generation, there is a roughly 60% discrepancy between the two methods might be found in the amount of primary energy. When renewables does not take up a major share in primary energy consumption, no major discrepancy is detected. But with the surge and increasing uptake of renewables in the future, significant variances will occur on the assessment of total energy consumption, energy conservation and substitution, prompting the need for further diagnosis and comparison. Table 9.6 compares the two methods of converting hydro, wind, solar and other renewables into primary energy [7].

Both statistical methods have considerable bearing on total energy demand and assessment on the contribution of energy conservation and energy substitution to CO_2 emission reduction. Converting renewable power into primary energy by coal equivalent calculation equivalent method underestimates the total energy demand, when comparing to the traditional method of coal consumption from power generation. Meanwhile, with the increase in share of renewables in primary energy, the method

Table 9.5 CO_2 emission reduction by sector under 2 °C target path and policy scenario (Unit: billion tons)

	2020	2030				2050			
		Policy scenario	2 °C target path	Emission reduction	Contribution (%)	Policy scenario	2 °C target path	Emission reduction	Contribution (%)
Industrial	3.77	4.54	4.15	0.39	45.3	3.69	1.19	2.50	34.7
Building	1.00	0.97	0.88	0.09	10.5	0.83	0.31	0.52	7.2
Transport	0.99	1.16	1.09	0.07	8.1	1.11	0.55	0.56	7.8
Others	0.21	0.40	0.38	0.02	2.3	0.16	0.04	0.12	1.7
Power	4.06	4.01	3.95	0.06	7.0	3.29	0.83	2.46	34.2
Industrial process	1.32	1.17	0.94	0.23	26.7	0.92	0.47	0.45	6.3
Forest carbon sinks	−0.58	−0.61	−0.61	0	0.0	−0.62	−0.7	0.08	1.1
CCS/BECCS	0	0	0	0	0.0	0	−0.51	0.51	7.1
Total CO_2 emissions	10.77	11.64	10.78	0.86		9.38	2.18	7.20	

Table 9.6 Primary energy consumption with different statistical methods

	2005		2020		2030		2050	
	Coal equivalent calculation	Calorific value calculation	Coal equivalent calculation	Calorific value calculation	Coal equivalent calculation	Calorific value calculation	Coal equivalent calculation	Calorific value calculation
Hydro, wind, solar power generation (trillion kWh)	0.5		2.1		3.6		9.6	
Conversion to primary energy (billion tce)	0.16	0.07	0.62	0.25	1.07	0.44	2.88	1.18
Non-fossil fuel (billion tce)	0.19	0.10	0.79	0.42	1.48	0.86	3.81	2.11
Total energy demand (billion tce)	2.61	2.52	4.94	4.57	5.98	5.35	5.20	3.50
Coal (%)	72.4	75.1	57.0	61.6	45.0	50.3	9.1	13.5
Oil (%)	17.8	18.5	18.5	20.0	17.0	19.0	7.7	11.4
Gas (%)	2.4	2.5	8.5	9.2	13.0	14.5	10.0	14.9
Non-fossil fuel (%)	7.4	3.9	16.0	9.3	25.0	16.1	73.2	60.2
CO_2 emissions (Gt CO_2)	6.06		10.03		10.46		2.93	

(continued)

Table 9.6 (continued)

	2005		2020		2030		2050	
	Coal equivalent calculation	Calorific value calculation	Coal equivalent calculation	Calorific value calculation	Coal equivalent calculation	Calorific value calculation	Coal equivalent calculation	Calorific value calculation
CO_2 emissions per unit of energy consumption ($kgCO_2$/kgce)	2.32	2.41	2.03	2.19	1.75	1.96	0.56	0.83
Decline of CO_2 emissions per unit of energy consumption(%)			0.89	0.62	1.44	1.12	5.52	4.18
Average annual decline of energy consumption per unit of GDP (%)			3.69	3.96	2.97	3.29	4.30	5.63
Decline of CO_2 intensity per unit of GDP (%)			4.55	4.55	4.40	4.40	9.60	9.60

Table 9.7 Comparison of metrics in 2050 with 2030 under two statistical methods

	Coal equivalent calculation	Calorific value calculation
Decline in total energy consumption (%)	13.0	34.6
Decline in energy consumption per unit of GDP (%)	58.7	68.9
Decline in CO_2 consumption per unit of energy consumption (%)	67.9	57.3
Decline in CO_2 consumption per unit of GDP (%)	86.7	86.7
Decline in total CO_2 emissions (%)	72.0	72.0

overestimates the decline in energy consumption per unit of GDP and underestimates the decline of CO_2 emissions per unit of energy consumption, thus transferring the emission reduction contribution from energy substitution to energy conservation and inflating the contribution of energy conservation to CO_2 emission reduction.

From 2030 to 2050, the generating capacity of hydro, wind, and solar will surge from 3.6 trillion kWh to 9.6 trillion kWh, with their share of power generation soaring to 73% from 38.9%. The total energy demand in 2050 measured by the two statistical methods is 5.2 billion tce and 3.5 billion tce respectively, with calorific value calculation method 1.7 billion tce less, or 32.7% lower than the method of coal equivalent calculation. This is not due to greater energy saving, but the difference in statistical method. From 2030 to 2050, energy intensity per unit of GDP is down by 58.7% and CO_2 emissions per unit of energy consumption is down by 67.9%, measured by the coal equivalent calculation method; whereas the calorific value calculation method calculate the decline at 68.9% and 57.3% respectively. During the same period, total CO_2 emissions from energy consumption will decrease by 7.53 billion tons, down 72.0%. By the coal equivalent calculation method, energy conservation contributes approximately 10% and energy substitution about 90% to the decline; whereas the calorific value calculation method puts their contribution at 33% and 67%, respectively (Table 9.7). Thus the latter method suggests an illusion of a greater contribution by energy saving. In this sense, when comparing and analyzing with similar international studies and global data, one should be mindful of the statistical methods used, as the results and conclusions produced by different methods mostly are not comparable.

9.2.4 Analysis on Transition of All Greenhouse Gas Emissions in 2 °C Target Path

Table 9.8 and Fig. 9.6 illustrate the structure and total amount of all GHG emissions under the 2 °C target path. Until 2030, total net greenhouse gas emissions remain at plateau at roughly 13.57 billion tCO_2, in which energy consumption-related CO_2

Table 9.8 Makeup of greenhouse gas emissions under the 2 °C target path (unit: $GtCO_2e$)

	2020	2030	2050
CO_2 emissions from energy consumption	10.03	10.46	2.92
CO_2 emissions from industrial processes	1.32	0.94	0.47
Non-CO_2 greenhouse gas emissions	2.44	2.78	1.76
Forest carbon sinks	−0.58	−0.61	−0.70
CCS + BECCS	0.00	0.00	-0.51
Net emissions	13.21	13.57	3.94

emissions stand at 10.46 billion tCO_2, emissions from industrial processes at 0.94 billion tCO_2, non-CO_2 emissions at 2.78 billion tCO_2e, and forest carbon sinks at 610 million tCO_2e. Energy consumption-related CO_2 emission remains the most important source of greenhouse gas emissions. In 2050, with the rapidly decarbonized energy mix, energy consumption-related CO_2 emissions, emissions from industrial processes, and non-CO_2 emissions are 2.92 billion, 470 million, and 1.76 billion tons respectively, down 71.9%, 57.3%, and 36.7% from the level in 2030. With the prospect of 700 million tons of forest carbon sinks and 510 million tons of CCS/BECCS, net greenhouse gas emissions in 2050 are estimated at 3.94 billion tCO_2e, 71% less than in 2030. In 2050, without taking into account agricultural and forestry carbon sinks and CCS, non-CO_2 greenhouse gases emissions make up 34% of total greenhouse gas emissions, compared with 16% today. Non-CO_2 emission reduction becomes an important source for curbing greenhouse gas emissions, providing the rationale for earlier technological planning.

In the long run, further technological breakthroughs are needed to reduce non-CO_2 GHG emissions, and effective new alternatives should be developed, which might rapidly drive down the cost of emissions reduction. Under the 2 °C target path, it is more important to strategically deploy research on non-CO_2 emission reduction technologies in advance, and explore more effective market mechanisms such as the carbon market to accelerate non-CO_2 emission reduction.

Compared with the policy scenario, the total greenhouse gas emissions without CCS and carbon sinks in the 2 °C target path by 2050 decreases by 61%, and the total greenhouse gas emissions with CCS and carbon sinks decreases by 69%, as shown in Table 9.9.

9.3 Analysis of Net Zero CO_2 Emissions Pathway Driven by the 1.5 °C Target

At present, the call for establishing and achieving the target of holding temperature rise below 1.5 °C has been getting stronger. Since the release of the IPCC *Special Report on Global Warming of 1.5 °C*, many countries have set out to layout and plan relevant strategies and goals for net zero emissions by the middle of this century. In

Table 9.9 Greenhouse gas emissions under the 2 °C target path and policy scenario in 2050 (unit: $GtCO_2e$)

	Policy scenario	2 °C target path
CO_2 emissions from energy consumption	9.08	2.92
CO_2 emissions from industrial process	0.92	0.47
Non-CO_2 greenhouse gas emissions	3.17	1.76
Forest carbon sinks	−0.62	−0.70
CCS + BECCS	0.00	-0.51
Net emissions	12.55	3.94

particular, European Union, aims to be the first regional block to have committed to going "climate-neutral" by 2050, and plays a leadership role of the global climate change progress. China, as the biggest emitter of greenhouse gases with aiming the goal of building a great modern socialist country by 2050, should undertake emission reduction obligations which commensurate with the rising national power and international influence. Based on the detailed analysis of the 2 °C target-oriented scenario in the previous section, this part is going to provide a further study and discussion on the 1.5 °C target-oriented scenario, including transition pathway towards net zero CO_2 emission goal by 2050 and also deep decarbonization of other greenhouse gases.

9.3.1 Scenario Analysis on 1.5 °C Target-oriented Net-zero Development Path

To bring about net-zero CO_2 emission of the energy system by 2050, as shown in Fig. 9.7, efforts should be made to achieve the carbon peak as soon as possible by 2030, and promptly transition to the emission pathway of the 1.5 °C scenario. Compared with the 2 °C target path, the 1.5 °C target-oriented net-zero development path (1.5 °C target path) shows more notable decline in direct CO_2 emissions of the energy system after 2030. From 2030 to 2050, CO_2 falls by 9.3% annually, 3.2 percentage point higher than the 6.1% in the 2 °C target path, meaning that the period should be characterized by greater decarbonization of the energy mix, and newly added non-fossil fuel consumption should rise by an extra 0.5 percentage point to reach an annualized 5.5% growth.

To achieve the 1.5 °C target path, the key lies in accelerating the rise of non-fossil fuels in primary energy consumption mix while curbing total energy use. Based on the 2 °C target path analysis in the previous section, greater efforts should be made in decarbonization of the energy mix to enable net-zero emission goal by 2050. The relevant indicators of economic, energy, and CO_2 emission are provided in Table 9.10.

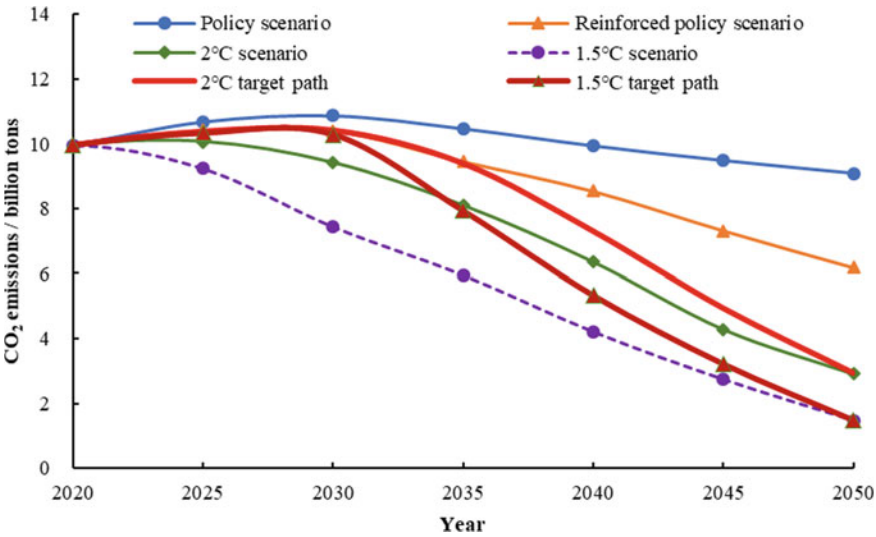


Fig. 9.7 Comparison of the 1.5 °C target path with other scenarios

To strive for net zero CO_2 emission by 2050, total energy consumption should peak around 2030, ideally under 5.87 billion tce, and energy consumption should also show a downward trend after 2030. In the meantime, decarbonization of the energy mix must accelerate, with coal, oil, natural gas, and non-fossil energy accounting for 45%, 17%, 13%, and 25% of primary energy consumption respectively in 2030, and 5.4%, 3.0%, 5.5%, and 86.1% respectively in 2050, with non-fossil energy making greater contributions. From 2030 to 2050, the annual energy consumption per unit of GDP can decrease at around 4%-5%, and the decline in carbon intensity of energy consumption brought by the decarbonization of energy mix can be improved from 4.4% in 2030 to 13.7% in 2050, playing a crucial role in achieving the net-zero emission in 2050. The total amount and composition of China's primary energy consumption under the 1.5 °C target path are shown in Fig. 9.8. After 2030, China should push for a quick reduction in its consumption of fossil energy, especially coal, and the installation of coal and other fossil energy units would risk massive early retirement and huge stranded costs.

Figure 9.9 and Table 9.10 illustrate the CO_2 emissions of major sectors under the 1.5 °C target path. After 2030, more notable carbon reduction is observed in all sectors. The industrial and power sector, in particular, need to strengthen their efforts in emission reduction. By 2050, with the contribution of 780 million tons of forest carbon sink and 880 million tons of CCS (BECCS), the economy-wide CO_2 emissions are reduced to about 60 million tons, basically achieving a net zero emission target.

Table 9.10 Indicators of economic, energy, and carbon dioxide emission under the 1.5 °C target path

Item (unit)		2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Annual GDP growth rate (%)			11.3	7.9	5.9	5.3	4.8	4.4	4.0	3.6	3.2
GDP index		1	1.71	2.50	3.33	4.31	5.45	6.75	8.22	9.81	11.48
Energy consumption (billion tce)		2.61	3.61	4.36	4.94	5.50	5.98	5.65	5.43	5.22	5.00
Energy consumption structure	Coal (%)	72.4	69.2	64	57.0	51.2	45.0	35.5	24.0	14.1	5.4
	Oil (%)	17.8	17.4	18.1	18.5	17.8	17.0	13.6	9.6	6.1	3.0
	Gas (%)	2.4	4	5.9	8.5	10.7	13.0	11.2	9.0	7.2	5.5
	Non-fossil fuel (%)	7.4	9.4	12	16.0	20.3	25.0	39.7	57.4	72.7	86.1
CO_2 emissions per unit of energy consumption ($kgCO_2$/kgce)		2.32	2.25	2.16	2.03	1.90	1.75	1.40	0.98	0.62	0.29
Annual decline of CO_2 intensity per unit of energy consumption (%)			0.58	0.83	1.24	1.37	1.59	4.37	6.92	8.85	13.76
CO_2 emissions (billion tCO_2)		6.06	8.13	9.38	10.03	10.45	10.46	7.93	5.33	3.21	1.47
Annual decline of energy consumption per unit of GDP (%)			4.15	3.82	3.09	2.97	2.97	4.93	4.60	4.26	3.92
Decline of CO_2 emissions per unit of GDP (%)			4.72	4.62	4.33	4.23	4.57	9.08	11.20	12.77	17.10
Decline from 2005 level (%)			21.5	38.0	50.3	60.0	68.3	80.6	89.3	94.6	97.9

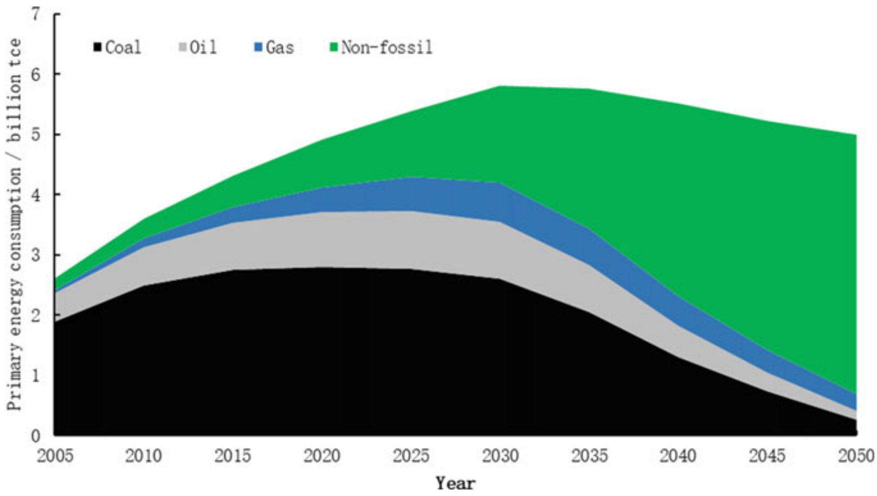


Fig. 9.8 Primary energy consumption and composition under the 1.5 °C target path

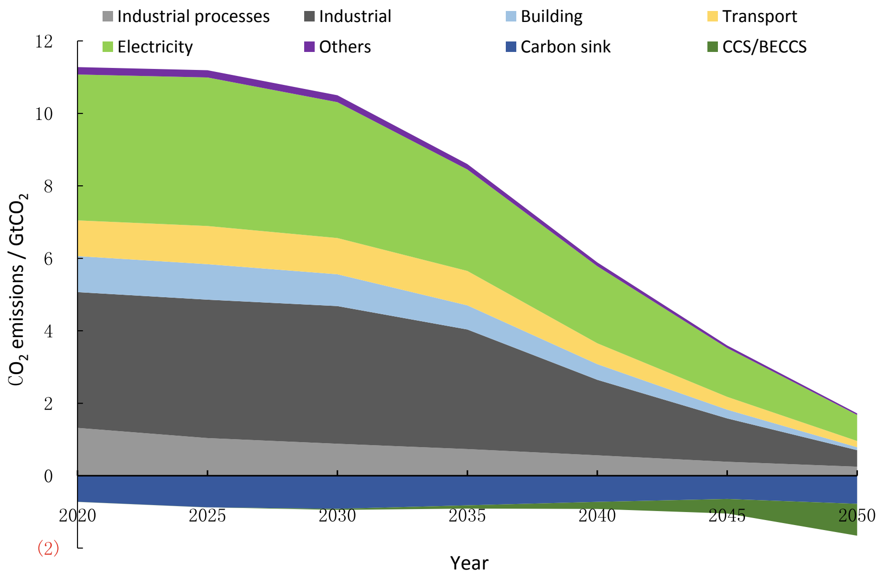


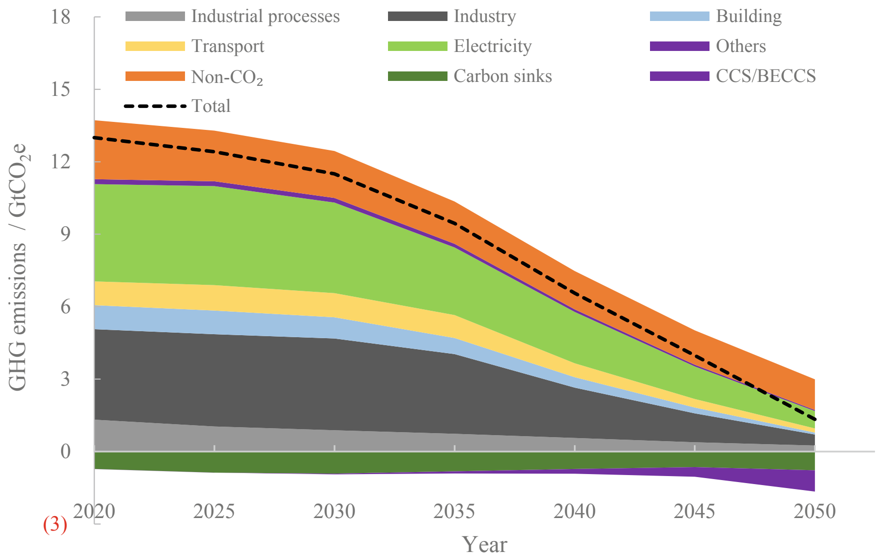
Fig. 9.9 CO_2 emission by sector in the 1.5 °C target path

9.3.2 Comprehensive Analysis on GHG Emissions in the 1.5 °C Target Path

Under the 1.5 °C target path, China's total greenhouse gas emissions and their composition in the future are shown in Table 9.11 and Fig. 9.10. In comparison with the 2 °C target path, total greenhouse gas emissions could drop to 1.33 billion CO_2e by 2050, of which energy-related CO_2 emissions make up approximately 1.47 billion tons and industrial process CO_2 emissions make up about 250 million tons. Forestry carbon sinks, CCS (BECCS), by and large, can offset CO_2 emissions from energy consumption and industrial processes, thereby achieving net zero CO_2 emission, other greenhouse gases will see an over 50% reduction from the peak, laying a solid foundation for net-zero emission of all greenhouse gases after 2050.

Table 9.11 All greenhouse gas emissions and their composition under the 1.5 °C target path (unit: $GtCO_2e$)

	2020	2030	2050
CO_2 emissions from energy consumption	10.03	10.31	1.47
CO_2 emissions from industrial process	1.32	0.88	0.25
Non-CO_2 greenhouse gas emissions	2.44	2.65	1.27
Forestry carbon sinks	−0.72	−0.91	−0.78
CCS + BECCS	0.0	−0.03	−0.88
Total emissions	13.07	12.90	1.33



(3)

Fig. 9.10 Greenhouse gas emissions by sector under the 1.5 °C target path

9.3.3 *Analysis on the Transition from the 2 °C Target Path to the 1.5 °C Target Path*

By 2050, the net CO_2 emissions under the 2 °C target path will be 2.18 billion tons, and the net greenhouse gas emissions will be 3.94 billion tCO_2e. As for the 1.5 °C target path, in addition to achieving net-zero CO_2 emissions all greenhouse gases emissions would also need to be reduced to 1.33 billion tCO_2e. Figure 9.11 depicts the efforts needed for further mitigation in various sectors under 1.5 °C target path. Data suggests that industrial sectors should see significant reduction in greenhouse gas emissions, building and transport should also strive for extreme reductions, and the remainder can be offset by further deployment of CCS/BECCS technologies. Under the 1.5 °C target path, non-CO_2 emissions are expected to drop further with technological breakthroughs, but the remaining emissions still run as high as 1.33 billion tCO_2e, which would become the main challenge of net-zero emission of all greenhouse gases. In the 1.5 °C target path, strengthening the R&D of groundbreaking non-CO_2 emission reduction technologies in advance is crucial for China to achieve neutrality in all greenhouse gases. The initial cost of non-CO_2 emission reduction is relatively low, and emission reduction can be quickly obtained. However, the cost of deep decarbonization is expected to be on a steep rise, requiring introduction of groundbreaking technologies. At the same time, breakthroughs and development of CO_2 direct removal (CDR) technology is necessary to secure net-zero emission of all greenhouse gases soon after 2050.

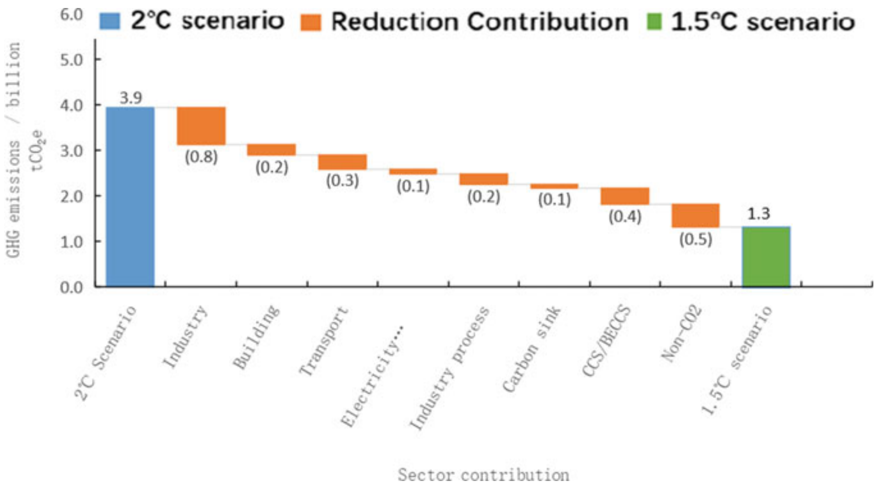


Fig. 9.11 Changes of sectoral contribution of emission reduction with shifting from the 2 °C target path to the 1.5 °C target path

9.4 Conclusions and Suggestions

(1) **Difficulties and Challenges for Deep Decarbonization**

Achieving "net-zero emission" by the middle of this century has become the goal of many developed countries, and the global efforts to cap the temperature rise within 1.5 °C have also gained more attention. At the end of 2018, the European Commission announced the target of "carbon neutrality" by 2050, and introduced "European Green Deal" policies package at the end of 2019 [8]. The UK also revised its Climate Change Act in 2019, incorporating "carbon neutrality" by 2050 into the Act, building the legal basis for deeper decarbonization of the UK [9]. The active advancement of the 1.5 °C-oriented net zero emission target in developed countries will not only accelerate their own low-carbon transformation of economy and society, but also bring challenges and pressure to developing countries and less developed nations for their efforts on this front.

The above analysis suggests that, China's long-term low-carbon transition pathway should compose of the short-term economic and social development with the long-term global temperature control targets set out in the Paris Agreement. It not only calls for greater reduction in greenhouse gas emissions in the 14th and 15th Five-Year Plans, but also further R&D of disruptive technologies including CCS/BECCS, large-scale energy storage, hydrogen energy, and smart grid to accelerate deeper decarbonization after 2030.

If the 1.5 °C target path proposed in this report is to be achieved by 2050, strengthened efforts should be made on top of the 2 °C target path. Compared with the 2 °C target path, the consumption of coal, oil, and natural gas should fall by another 42.9%, 62.5%, and 47.0%, whereas non-fossil energy should grow by another 13.2%, and the share of non-fossil in primary energy consumption should rise to 86.1%. To enable deeper emission reduction, aside from applying necessary CCS in the power sector and industrial processes, BECCS technology should be applied in the power sector, and hydrogen production from renewable energy and hydrogen energy as secondary energy should be used in fuel cell freight and steelmaking processes. However, these new technologies are hampered by the barriers of technological development, as well as uncertainties in the market penetration, which also brings major challenges to deep decarbonization.

(2) **Work Plans for Long-term Low-carbon Transformation**

China's long-term low-carbon transformation pathway should not only be consistent with the stage and characteristics of its socio-economic development, but also linked with the process of socialist modernization. It needs to accommodate both domestic and international interests and deploy futuristic competitive strategy. Before 2030, NDC targets need to be enhanced to balance social-economic development efforts in and energy conservation and carbon reduction, and cap both the intensity and total amount of CO_2 emissions to push for high-quality transformation. In addition, great efforts should be taken to step up the R&D of technologies and capacity building to lay a more comprehensive and solid groundwork for deeper decarbonization after 2030. Post- 2030, China should aim for the net-zero CO_2 emissions, and deep decarbonization for non-CO_2 greenhouse gases. Manage all metrics of China's socio-economic development, and strive to fulfill the responsibilities of a major power commensurate with its comprehensive national strength by 2050. Key recommendations for China's long-term low-carbon transformation.

(1) Strengthen the strategy-oriented development. The transformation of future socio-economic development should be strategy-oriented, with the low-carbon strategy embedded in every aspect of socio-economic development. Low-carbon strategy should be aligned in a timely and phased manner with the national long-term development strategy, and assigned to every five-year planning as well as sub-national strategies, thereby connecting the long-term low-carbon strategy and the short-term socio-economic development to form a new paradigm where the two promote and coordinate each other.
(2) Prioritize technological development. Technological development and revolutions will direct influence on the progress and results of global low-carbon transformation. Therefore, attention must be placed on the R&D of technologies, with adequately preparation for comprehensive low-carbon transformation. Particular focus should be placed on the R&D and demonstration of forward-looking technologies such as large-scale renewable energy grid connection, hydrogen energy, energy storage, smart grid, CCS/BECCS/DACCS, etc., to secure the bottleneck breakthroughs and technology industrialization, further enhance the international competitiveness of China's advanced technologies, and showcase China's contributions to the global low-carbon transformation.
(3) Boost capacity building. With the improvement of China's comprehensive national power, climate change actions should gradually expand to the entire economy and all greenhouse gases in order to demonstrate China's contribution as a responsible power. This requires an all-round strengthening of China's capacity to tackle climate change, including capacity building for greenhouse gas measurement, verification and reporting, enhanced government's capacity to climate change response and more active engagement and practices of the private sector.
(4) Enhance institutional framework. Strengthen institutional building, promote climate change legislation, provide stronger legal ground for climate change efforts, and boost synergies in addressing climate change and improving environmental quality. Build stronger carbon trading market, and better harness market forces to cut carbon emissions. Facilitate the coordination and integration of climate policies with those related to socio-economic development and environmental protection, and leverage the synergy of policy systems.
(5) Promote comprehensive and active all stakeholders participation. Step up education, publicity and training to further enhance the awareness, understanding, and support of the general public in addressing climate change, and encourage low-carbon consuming behavior and lifestyle. Create an enabling

environment for low-carbon participation and provide broader space for various stakeholders to take low-carbon actions actively.

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