A Vision for Regional Energy Management Systems in China for the Period of 2025-2035

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Gist

China is now the world's largest emitter of carbon dioxide, accounting for 28% of global emissions as of 2019. In 2020, China declared its goal to peak carbon emissions before 2030 and achieve carbon neutrality around 2060 (3060 goal).

To achieve this goal, in terms of energy supply, a major direction is to shift from fossil energy to clean energy, such as wind, solar, hydroelectric, and nuclear power. On another front, in terms of demand side, the major direction is the promotion of energy conservation and the shift from fossil energy to electric energy and non-fossil energy, including hydrogen energy and carbon capture or recycling.

The Chinese government has so far focused on decarbonization and electricity liberalization. That effort led the government to put together 10 key actions for peak carbon emissions by 2030, as well as the establishment of an electricity trading market through power restructuring.

In order to achieve carbon neutrality around 2060, China must take further measures to achieve the 1.5°C to 2°C scenario target.

First, for the industrial sector, decarbonization is more difficult than in other sectors. Therefore, it is necessary to develop advanced breakthrough technologies, such as zero-carbon steelmaking using hydrogen to curb carbon dioxide emissions resulting from industrial processes, with shifting energy sources from fossil to electric. In the power sector, on the other hand, Carbon dioxide Capture and Storage, or CCS, and

the massive deployment of variable renewable energy sources are both important. In order to connect a large amount of variable renewable energy sources to the grid, the implementation of a solution, such as the use of flexibility is desirable, in addition to strengthening the grid infrastructure through technologies, such as UHV, HVDC. In other words, in order to achieve both the massive deployment of variable renewable energy sources and stable power supply, it is considered necessary to ensure flexibility through grid stability control systems and smart inverters.

Note: This paper is the result of the first phase of the Tsinghua University collaboration (2019-2021).

1. Trends of energy and CO_2 emissions

Owing to its rapid economic development and urbanization, China is currently the largest carbon emitter in the world, accounting for 28% of global CO_2 emissions in 2019 [1](Fig 1a). Its CO_2 emissions surpassed those of the US in 2007, and those of the US, the 27 European Union countries (EU27) and the UK combined in 2012, reflecting an increase of 45% from 2007 to 2013 [2]. It was thought that China's CO_2 emissions had peaked, as suggested by the negative growth rates observed from around 2013 to 2016 [2][3][4]. However, a rebound in emissions thereafter suggests that long-term reduction remains a key policy challenge for China and the world.

Carbon emissions in China have evolved alongside socio-economic development. Before 1970, China's total CO_2 emissions were smaller than 900 million tons CO_2, and per capita emissions were roughly a quarter of the global average. However, since the reform and opening-up in the 1970s, and particularly after joining the World Trade Organization (WTO) in 2000, the economy grew rapidly along with CO_2 emissions (Fig 1a). Indeed, CO_2 emissions in China increased by an average of 10% in the 1970s, 5% in the 1980s, 3% in the 1990s, 9% in the 2000s and 3% in the 2010s. Meanwhile, per capita CO_2 emissions also increased, experiencing rapid growth during 2000–2013 and stabilization thereafter (Fig 1b). Concurrently, carbon intensity (CO_2 emissions per GDP) exhibited a downward trend since 1980 (Fig 1c). As of 2019, these key features culminated in CO_2 emissions of 10.3 billion tons CO_2 (±13%, confidence interval (CI) = 90%) and per capita CO_2 emissions of around 7.4 tons CO_2 [5] (Fig 1d).

In 2020, China declared to achieve carbon peak out before 2030 and carbon neutrality around 2060 (30-60 decarbonization goals). China will give a gap of about 30 years between the two targets, and it is the shortest gap in the world. In comparison, the gap for the EU will be 71 years, the United States 43 years and Japan 37 years [6].

China aims to gradually increase the share of non-fossil energy consumption to around 20% by 2025, around 25% by 2030, and over 80% by 2060. Carbon dioxide

emissions per unit of GDP will be lowered by 18% from the 2020 level by 2025 and will have dropped by more than 65% compared with the 2005 level by 2030 [7].

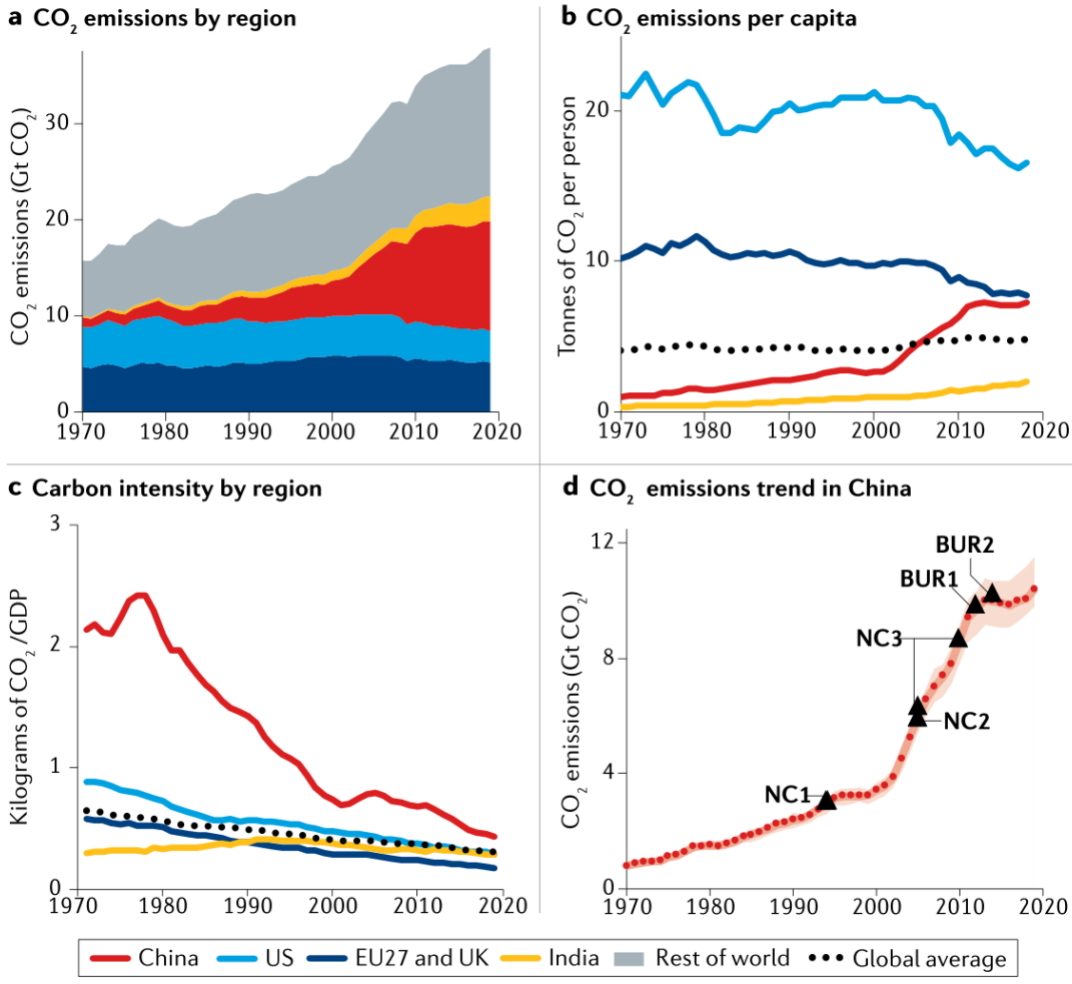

Fig 1 | China's carbon emission trend. a | Annual CO_2 emissions from fuel combustion and cement production in major emitting regions. b | CO_2 emissions per capita in major emitting regions. c | Carbon intensity (carbon emissions per economic output) for major emitting regions. d | CO_2 emissions trends in China, from the GCP, IEA, BP, EDGAR, CDIAC and CEADs databases, and years in

which emission inventories were submitted to the UNFCCC via National Communications (NC) and Biennial Update Reports (BUR). Red shading represents uncertainties among databases. China's share in global CO_2 emissions has increased rapidly since about 1980, with emissions per capita increasing substantially during the 2000s, but plateauing and fluctuating since 2010.

From the supply side point of view, major trend is shifting from fossil energy to clean energy including wind, solar, hydro, and nuclear. It will be mandatory for fossil fuel based electric generator to have the function of carbon capturing in the future. According to GEIDCO, the share of fossil fuel generator capacity will decline from 53.5% in 2020 into 42.5% in 2025, 32.5% in 2030, 8.4% in 2050, and 4.0% in 2060, and the share of clean energy based electric generator capacity will increase from 43.4% in 2020 into 57.5% in 2025, 67.5% in 2030, 92% in 2050, and 96% in 2060. Especially the capacity of wind and solar generator will remarkably increase from 12.7% and 11.3% in 2020 into 31.2% and 47.4% in 2060 respectively [8].

From the demand side point of view, major trends are energy saving, energy shifting from fossil energy to electricity and non-fossil energy such as hydrogen, and carbon capturing or carbon recycling.

Wind and solar in China have already been cost-competitive compared with fossil generating sources [9]. Especially solar is the most competitive and so both distributed photovoltaic (PV) and centralized PV are expected to be most widely penetrated hereafter. In 2021, newly installed distributed PV accounted for 55% of all newly installed PV capacity, exceeding half for the first time in Chinese history, mainly around the areas of east populous provinces (Shandong, Hebei, Henan, Anhui, Zhejiang, Jiangsu, Beijing, Shanghai, etc.) [10].

The representative of demand side shifting from fossil energy to electricity is an electric vehicle (EV) and a plug-in hybrid vehicle (PHV). In China, EV and PHV are categorized into New Energy Vehicle (NEV) and they accounted for 99.8% of

NEV in 2019. According to "Technology Roadmap 2.0 for Energy Saving and New Energy Vehicles" released by China Society of Automotive Engineers, China's auto industry carbon emissions will peak ahead of the national carbon emission reduction commitment around 2028, and the total carbon emissions will drop by more than 20% from the peak by 2035. Besides, it was proposed that by 2035, the NEV market will account for 50%, the number of Fuel Cell Vehicles (FCV, also categorized into NEV) will reach about 1 million, the conventional vehicles will be fully hybridized, and the automobile industry will achieve electric transformation [11].

2. Government policy for carbon neutrality

2.1 Decarbonization

Emissions Trading Scheme (ETS) has been started for power generation sector in July 2021 and Green Power Trading Scheme has been started by two major electric power companies in September 2021.

The government of China came up with the following 10 major actions for carbon peak-out before 2030 [12]:

- The action for green and low-carbon energy transition
- The action for energy savings, carbon emission mitigation and efficiency improvement
- The action for peaking carbon dioxide emissions in industry sector
- The action for peaking carbon dioxide emissions in urban-rural development area
- The action for promoting green and low-carbon transportation
- The action for promoting circular economy in carbon mitigation purpose
- The action for advancing green and low-carbon technology innovation

- The action for consolidating and enhancing carbon sink
- The action for green and low-carbon society
- The action for promoting all regions to peak carbon dioxide emissions hierarchically and orderly

2.2 Electric power deregulation

Through the electric power system reform, electricity market has been established in China and electric power deregulation is in progress. Now, the number of electricity retailers, electricity exchanges and trading participants in China have already surpassed those in Japan, respectively.

3. Pathway to carbon neutrality

There are four scenarios for long-term low-carbon transition as follows:

- **Policy scenario:** Based on the NDC objectives, action plans and related policies proposed by China under the Paris Agreement, continue the current low-carbon transition trend and policy scenario
- **Strengthen the policy scenario:** On the basis of the Policy scenario, further strengthen the intensity and extent of reducing the energy intensity and carbon dioxide intensity of GDP, and further increase the proportion of non-fossil energy in primary energy consumption and other indicators
- **2 ℃ temperature control target scenario:** To achieve the goal of global temperature control of 2 ℃ temperature rise
- **1.5 ℃ temperature control target scenario:** Guided by the goal of controlling 1.5 ℃ temperature rise, we will strive to achieve zero net carbon dioxide emission and deep emission reduction of other greenhouse gases by the middle of the 21st century

CO2 emissions by sector and primary energy consumption by energy source under

different scenarios are shown in Fig 2 and Fig 3 respectively [13]. In 2050, although primary energy consumptions in the scenarios of 2 ℃ target and 1.5 ℃ target are not so small compared to other scenarios, CO2 emissions of the two scenarios are significantly smaller than others. To achieve the carbon neutral target around 2060, it will be necessary for China to take measures for between 2°C and 1.5°C targets.

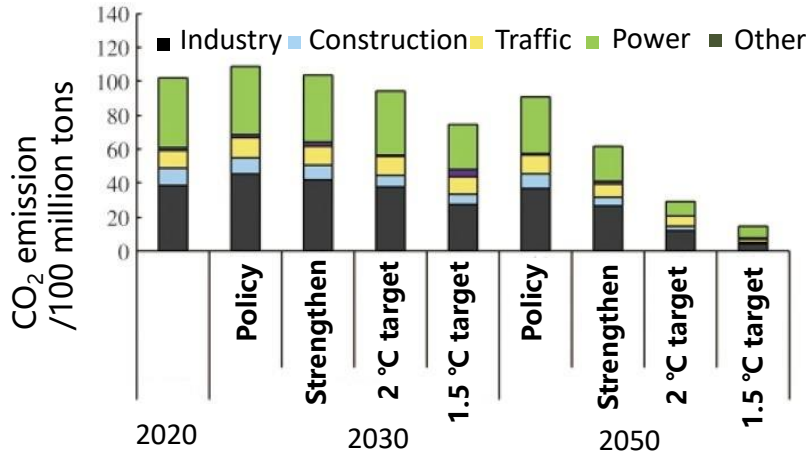

Fig 2 Composition of CO_2 emissions by sector under different scenarios

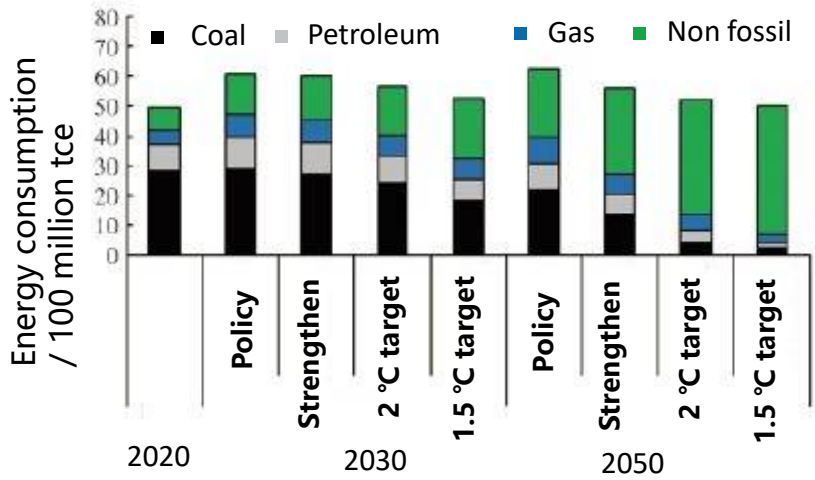

Fig 3 Composition of primary energy consumption by energy source under different scenarios

CO_2 emissions from different sectors (power, construction, industry, transportation) under different scenarios are shown in Fig 4 to Fig 7 respectively [13].

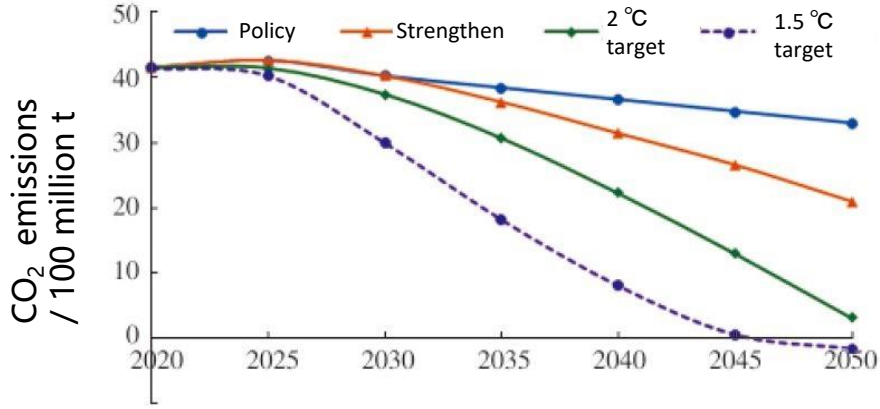

Fig 4 CO_2 emissions from power sector under different scenarios (including CCS)

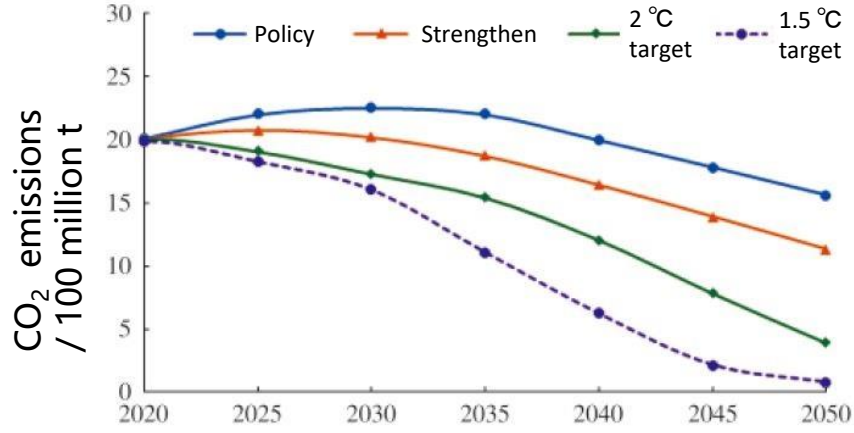

Fig 5 CO_2 emissions (including indirect emissions) from construction sector under different scenarios

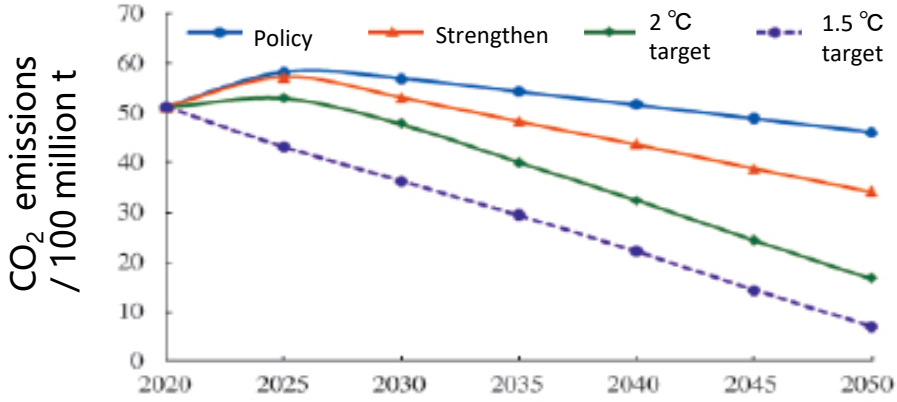

Fig 6 CO_2 emissions from industrial sector under different scenarios

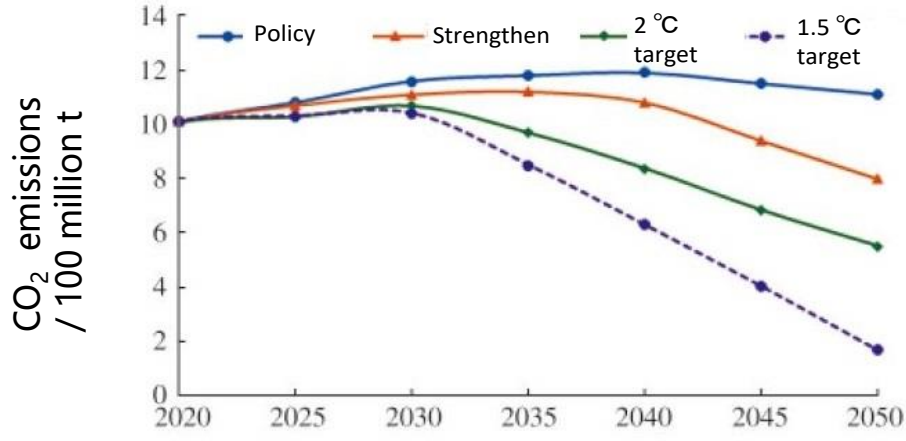

Fig 7 CO_2 emissions from transportation sector under different scenarios

In the scenarios of 2 ℃ target and 1.5 ℃ target, CO2 emissions from power sector (including CCS) are most rapidly reduced compared to other sectors and CO2 emissions from industrial sector are most slowly reduced. It shows the difficulty of the decarbonization in industrial sector. To reduce carbon emissions from industrial processes, such as iron and steel, cement, and chemicals, it is necessary to develop advanced breakthrough technologies, such as zero-carbon iron-making technology

using hydrogen. Besides, energy shifting from fossil fuel to electricity is necessary.

In power sector, not only CCS but also Variable Renewable Energy (VRE: wind and solar) should be penetrated. In most cases, VRE is integrated to the grid. Major challenges for grid integration of VRE are the instability of generation due to weather condition and the overloading due to uneven distribution of VRE locations. The promising solutions are the reinforcement of the grid infrastructure such as UHV and HVDC, and the utilization of flexibility with pumped storage hydropower and Distributed Energy Resource (DER) such as battery, EV, building and so on. In 2021, China government proposed "Integration of Power generation, Grid, Load and Storage" as the utilization of flexibility [14]. In the case of high penetration of VRE, innovative technologies such as grid stability control systems, smart inverters and Distributed Energy Resource Management Systems (DERMS), which provides diverse system services corresponding to the state of the electric network through autonomous or remote control, will be necessary for stable power supply [15].

4. Conclusions

China is currently the largest carbon emitter in the world, accounting for 28% of global CO2 emissions in 2019. In 2020, China declared to achieve carbon peak out before 2030 and carbon neutrality around 2060 (30-60 decarbonization goals).

The major trend for supply side is shifting from fossil energy to clean energy including wind, solar, hydro, and nuclear, and the major trends for demand side are energy saving, energy shifting from fossil energy to electricity and non-fossil energy such as hydrogen, and carbon capturing or carbon recycling.

The government of China has been promoting the efforts to decarbonization as well as to electric power deregulation. The government came up with 10 major actions for carbon peak-out before 2030 and electricity market has been established through the electric power system reform.

To achieve the carbon neutral target around 2060, it will be necessary for China to take measures for between 2 °C and 1.5 °C scenario targets.

The decarbonization in industrial sector is more difficult than other sectors. To reduce carbon emissions from industrial processes, it is necessary to develop advanced breakthrough technologies, such as zero-carbon iron-making technology using hydrogen, and to shift energy source from fossil fuel to electricity. In power sector, both CCS and high penetration of VRE are crucial. The promising solutions for VRE integration to the grid are the reinforcement of the grid infrastructure such as UHV and HVDC, and the utilization of flexibility with pumped storage hydropower and Distributed Energy Resource (DER) such as battery, EV, building and so on. Especially for best use of the flexibility to achieve stable power supply, innovative technologies such as grid stability control systems, smart inverters and Distributed Energy Resource Management Systems (DERMS) will be necessary.

5. References

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Symbols and Abbreviations

CCS: Carbon Capture and Storage
DER: Distributed Energy Resource

ETS: Emissions Trading Scheme
EV: Electric Vehicle
FCV: Fuel Cell Vehicle
GEIDCO: Global Energy Interconnection Development and Cooperation Organization
GDP: Gross Domestic Product
HVDC: High Voltage Direct Current
NDC: Nationally Determined Contribution
NEV: New Energy Vehicle
PHV: Plug-in Hybrid Vehicle
PV: Photovoltaic
UHV: Ultra High Voltage
VRE: Variable Renewable Energy