



Peak energy consumption and CO₂ emissions in China's industrial sector

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ABSTRACT

China's industrial sector accounts for more than half of the country's final energy demand. Thus, controlling its energy consumption and carbon dioxide (CO₂) emissions is critical for achieving China's Paris Agreement target. We developed two scenarios for this sector's energy consumption and CO₂ emissions up to 2050 by inputting China's current macroeconomic, industrial de-capacity, energy efficiency, and policy requirements into a modified global change assessment model. Our quantitative analysis indicated that the industrial sector's energy consumption and CO₂ emissions growth will peak by 2025, subsequently declining. In the first reference scenario, peak energy consumption and CO₂ emission values in 2025 will be 2.42 gigatons of coal equivalent (Gtce) and 4.43 gigatons of CO₂ (GtCO₂), respectively. In the second low-carbon scenario, these peak values in 2025 will be 2.28 Gtce and 4.13 GtCO₂, respectively, that is, 5% and 7% lower than the respective values in the first scenario. After 2025, energy consumption and CO₂ emissions will decrease gradually up to 2050. Measures required to achieve low-carbon peak targets include policies for adjusting and optimizing the industrial structure, promoting low-carbon energy, and capping energy and coal use, and CO₂ emissions in this sector.

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1. Background

Climate change is a major global environmental issue. The Paris Agreement, signed in December 2015, stipulated that all participating countries should enhance their global response to the climate change threat, with the aim of keeping the global average temperature rise within 2 °C above pre-industrial levels, and preferably limiting it to 1.5 °C [1]. Increased efforts to reduce global greenhouse gas emissions and achieve an early global emissions peak value are required to reach this target. At the same time, developing countries can more or less stabilize their carbon dioxide (CO₂) emissions by 2025, subsequently reducing them [2].

Improved living standards in China along with accelerating industrialization and urbanization have led to steady increases in energy consumption and CO₂ emissions. In 2014, China's total energy consumption (4.26 Gtce) and CO₂ emissions (9.76 GtCO₂, the highest globally) respectively accounted for 23.0% and 27.5% of

global energy consumption and CO₂ emissions [3]. China's peak emissions targets are stated in the US-China Joint Statement on Climate Change, issued in November 2014, and in *Enhanced Action on Climate Change – China's Intended Nationally Determined Contributions* (a report on China's plans to fight climate change submitted to the UNFCCC Secretariat in June 2015). Accordingly, China's goal is to reach a CO₂ emissions peak in early 2030, by which time CO₂ emissions per unit gross domestic product (GDP) would be 60–65% below their 2005 levels [1].

Many researchers have used integrated assessment models to develop future scenarios of China's long-term (2030 and beyond) energy consumption and CO₂ emissions [4–13]. Most of these studies focus on nationally aggregated energy consumption and CO₂ emissions, with limited information available on individual industrial subsectors. Several researchers have also analyzed China's peak energy consumption and CO₂ emissions. Most of these studies used the Kaya/IPAT method (based on several high aggregated factors, such as population, GDP, energy intensity of per unit GDP, and CO₂ emissions of per unit energy) or similar models [14–19]. In addition, system dynamics model [20], FAIR/TIMER model [21], elasticity of energy method [22], energy supply-and-demand model [23], IMAC model [24] and index decomposition [25] model have been used to analyze China's peak energy

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Glossary

CCS	Carbon capture and storage
CO ₂	Carbon dioxide
GDP	Gross domestic product
EIA	Energy Information Administration
IEA	International Energy Agency
OECD	Organization for Economic Co-operation and Development
Gtce	Gigatons of coal equivalent
GtCO ₂	Gigatons of carbon dioxide
MtCO ₂	Million tons of carbon dioxide
TWh	Terawatt hours
HEI	High energy-intensive
CHP	Combined heat and power
CERS	China Energy Research Society
ETS	Emission trade system

consumption and CO₂ emissions. However, these studies, like previous studies, are integrated at national or regional levels, thus providing no detailed sectoral information, notably for the industrial sector.

Some studies have disaggregated the industrial sector into subsectors, such as steel, cement, chemicals, aluminum, and paper [26]. However, energy service demands for most sectors are based on historical data up to 2005. Consequently, they do not reflect rapid developments in subsequent years that impact on China's current macroeconomic, industrial de-capacity, energy efficiency, and policy requirements. There is little available information on energy-intensive industrial sectors and their contributions, (e.g., by year and emission amount) to China's announced peak emissions target. The IEA's annual *World Energy Outlook* report and the EIA's annual *International Energy Outlook* report, both of which focus on the next couple of decades, are similarly vague in their characterizations of industrial energy use in China [27], [28].

Compared with other sectors, industrial energy modelling has received less attention because of the diversity of subsectors, the impacts of energy-saving measures on product quality, and statistical issues [29]. Several studies have investigated the driving force propelling China's energy and CO₂ emissions growth, showing that the main drivers are the economic structure and activity (GDP) and energy intensity [30–35].

A study entailing a comparative analysis across different sectors and industrial subsectors in China revealed that industrial growth determined the status and future trend of carbon emissions. China's industrial sector (including the power subsector) accounted for about two-thirds of China's final energy consumption in 2015 [3]. Moreover, it also accounted for about half of China's final energy demand (including industry, building, and transportation), even excluding the power subsector as defined by IEA. This ratio value evidently differs at the global level, accounting for a third of the final energy consumption [27]. Studies have shown that global industrial energy use will continue to increase by 40–80% from 2009 to 2050 [36], with China's industrial energy use accounting for one-third of global industrial energy use [27]. Thus, the industrial sector can potentially be a major contributor to future CO₂ emission reductions in China, and even globally. Therefore, the above-mentioned goals entail daunting challenges and depend heavily on the emission reduction efforts of China's industrial sector.

To sum up, a more detailed analysis of China industrial sector is required to precisely identify energy consumption and CO₂ emissions of various subsectors (e.g., steel, cement, aluminum,

chemicals, and paper), because of their obviously different fuel structures, energy efficiency, and cost parameters. China's international commitments regarding climate change and the latest demand for industrial transformation and upgrading of energy-intensive industries also require further consideration.

In this context, this study was aimed at investigating future energy consumption and CO₂ emissions in China's industrial sector. Specifically, the study addressed the following three questions. (1) When will the industrial sector's CO₂ emissions peak? (2) What will be the magnitude of that peak and what is the long-term role and trajectory of this sector after peak emissions are reached? (3) How can peak emissions targets for the industrial sector be achieved?

We applied a modified global change assessment model (GCAM) (<http://www.globalchange.umd.edu/models/gcam/download/>) to explore peak energy consumption and CO₂ emissions in China's industrial sector, based on current macroeconomic, industrial de-capacity, energy efficiency, costs, and policy requirements. Applying this model enabled a detailed consideration of energy-intensive sectors that will influence future emission pathways in China's industrial sector. The remainder of this paper is organized as follows. In section 2, we describe our research methods and scenarios. In Section 3, we present our data and key assumptions. In Section 4, we discuss our research results, explaining how the peak emission target can be realized. Section 5 offers conclusions and key policy recommendations.

2. Model and scenario description

2.1. Model description

For our study, we extensively modified China's industrial sector based on the GCAM (released version) model and added several modules, including the input module for key variables, the scenario module relating to key considerations, and the output module for energy consumption and CO₂ emissions. These modules were integrated to provide a complete analytical tool for examining energy consumption and CO₂ emissions of China's industrial sector, as shown in Fig. 1.

Module 1 (the input module) provided the key drivers of the industrial sector's end-use energy demand, which included key variables and parameters, such as population, GDP growth, and energy efficiency.

Module 2 (the modelling module) was based on the GCAM (released version) and entailed a consideration of China's actual situation in recent years. The original well-integrated industrial model for the region of China was modified and divided into seven subsectors to facilitate an assessment of energy consumption and CO₂ emissions by sector and fuel type. This is discussed in detail in section 2.2.1.

Module 3 (the scenario module) was applied as a scenario generator, considering peak emission constraints, de-capacity, and other policy requirements. The different scenarios also accounted for uncertainty and experts' future evaluations and different energy service demands (including the major outputs of energy intensive subsectors).

Module 4 (the output module), which was designed to visualize the results of final energy consumption and direct CO₂ emissions of the industrial subsectors.

2.2. Model application

2.2.1. GCAM description

As a popular integrated assessment model, GCAM has been extensively applied within studies at the regional level (e.g., China and the United States) and sectoral level [37–39]. Many studies

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