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Coronavirus pandemic reduced China's CO₂ emissions in short-term, while stimulus packages may lead to emissions growth in medium- and long-term

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HIGHLIGHTS

- We estimated CO₂ emission reductions in different sectors in China due to COVID-19.
- Industry sector contribute the most significant absolute CO₂ emission decrease.
- Energy-related CO₂ emissions decreased by 18.7% (182 MtCO₂) in first quarter of 2020.
- Economic stimulus packages may increase CO₂ emission growth rate in coming years.

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ABSTRACT

Coronavirus has confined human activities, which caused significant reductions in coal, oil, and natural gas consumptions in China since January of 2020. We compile industrial, transport, and construction data to estimate the reductions in energy-related CO₂ emissions during the first quarter of 2020 in China. Our results show that the fossil fuel related CO₂ emissions decreased by 18.7% (182 MtCO₂) in the first quarter of 2020 compared with the same period last year, including reductions of 12.2% (92 MtCO₂) in industry sectors, 61.9% (62 MtCO₂) in transport, and 23.9% (28 MtCO₂) in construction. The figure in annual CO₂ emission reductions is expected to limit with an estimate of 1.6%. However, to achieve the economic target for the 13th Five-Year-Plan, stimulus packages including investments in “shovel-ready” infrastructure projects issued by China's central and local governments to response the COVID-19 may increase CO₂ emissions with a higher speed in the coming years. Thus, sustainable stimulus packages are needed for accelerating China's climate goals.

1. Introduction

Coronavirus disease 2019 (COVID-19) is an infectious disease that has been creating panic over the last few months and had led to about 193,000 deaths and more than 2,800,000 confirmed diagnosis worldwide by the end of April 2020 [1]. Chinese government has adopted prompt and effective confined measures to limit the spread of the virus (Fig. 1). Although the effect of enforcing these aggressive measures to control the transmission in China and the world is undoubtedly enormous, the economic impacts of this disease outbreak were significant too. Every sector of the economy – from industry, transport, and construction, to catering services – has been feeling the effects. The

epidemic has shut factories, disrupted travels, closed construction sites, cut off communities, and shook up economic markets. As a result, the preliminary accounting of China's GDP decreased by 6.8% in the first quarter of 2020 year-on-year, in which the growth rates of primary, secondary, and tertiary industries were –3.2%, –9.6% and –5.2%, respectively [2]. Besides, the economic activities were nearly at a standstill in China, which reduced energy consumptions and related CO₂ emissions as well. In this study, we estimated how much the CO₂ emissions decreased in the first quarter compared with the same period of last year due to the COVID-19 and then analysis the possible effect on CO₂ emissions in medium- and long-term in China.

Accommodation and restaurant suffered the most as their output

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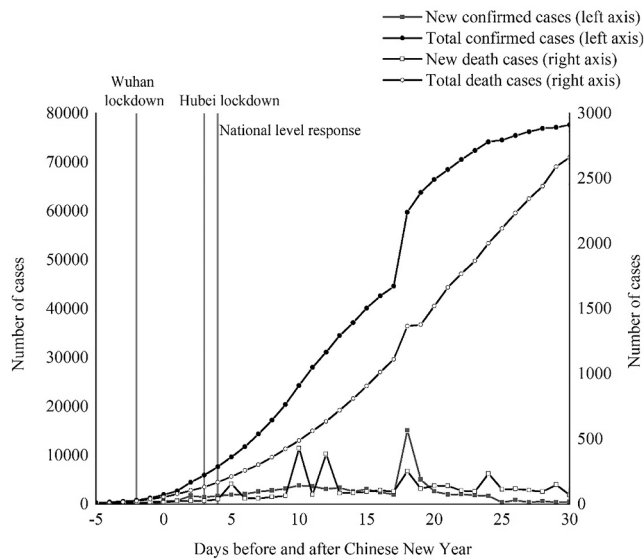


Fig. 1. Confirmed and death cases in China. X-axis shows days before and after Chinese New Year in 2020. The three vertical grey reference lines refer to Wuhan lockdown in January 23, Hubei lockdown in January 28, and National level response launched in January 29, respectively. Data Source: National Health Commission.

dropped by 35.5% in the first quarter of this year. Fear of the epidemic kept people at home and tourists away. Moreover, local governments have taken different degrees of traffic control measures to reduce the flow of people, and most people in China were restricted on movement and enforced home quarantine for two weeks or longer. Output in wholesale and retail trades were secondly most affected, which reduced by 17.8% in the first quarter. Real estate has been hit hard with a -6.1% growth rate in the first quarter compared with the same period last year [2]. In addition, the daily trading area of commercial housing in China's 30 large- and medium-sized cities fell by 34% on the first quarter year-on-year (Fig. 2).

Meanwhile, import and export have also been significantly impacted by the epidemic. According to the General Administration of Customs of

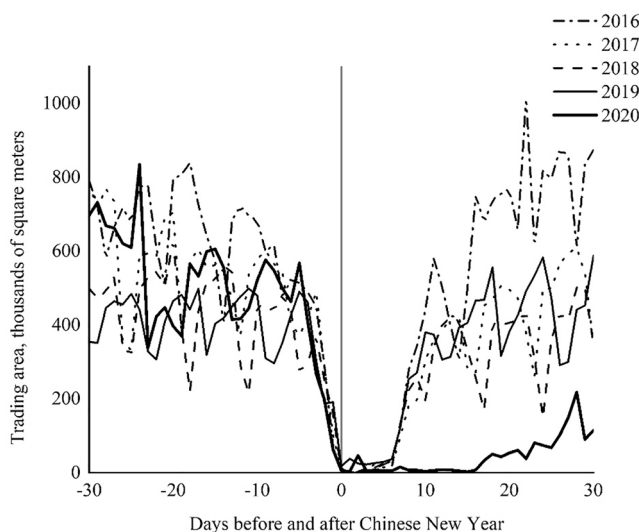


Fig. 2. Trading area of commercial housing in 30 large- and medium-sized cities. Daily trading area of commercial housing in 30 large- and medium-sized cities around the Chinese New Year period, in 1000 square meters per day. X-axis shows days before and after Chinese New Year, which located in different dates in different years. Data Source: WIND Information.

China, in the first quarter of this year, China's foreign trade volume in goods was RMB 6.57 trillion, dropped by 6.4% year-on-year (similarly hereinafter). Among them, exports were RMB 3.33 trillion, decreased by 11.4%; imports were RMB 3.24 trillion, reduced by 0.7%. The trade deficit was RMB 98.33 billion, dropped by 80.6% [3].

History indicates that economic downturns tend to lead to a temporary decline in CO₂ emissions, and then, there will be a rapid growth in CO₂ emissions after the downturns with the economic recover [4]. The global financial crisis of 2008–2009, for example, was accompanied by a temporary decrease (-1.4%) in global CO₂ emissions, and the emissions from fossil-fuel combustion and cement production grew by 5.9% in 2010, which was the highest total annual growth recorded since 2003 [5]. As for this crisis, the epidemic has led to reductions in energy consumptions and industry outputs, which indicates a reduction in CO₂ emissions in short-term, while the medium- and long-term emissions will depend on the government's actions and stimulus packages after the pandemic. The International Monetary Fund and Energy Information Administration (EIA) forecasted that the global CO₂ emissions would increase by 5.8% in 2021.

Many researchers have studied the changes in energy demand and related CO₂ emissions due to the COVID-19 both at the global and national levels. From a global perspective, Le Quéré et al. used government policies and activity data to estimate the decrease in CO₂ emissions during forced confinements and reported that the CO₂ emissions would decrease by 4% if pre-pandemic conditions return by mid-June, and decrease by 7% if some restrictions remain worldwide until the end of 2020 [6]. International Energy Agency showed that the global energy demand decreased by 3.8% during the first quarter of 2020 compared the same period of 2019 and the annual energy demand would decline by 4–6% in 2020 [7]. Liu et al. also provided a prediction on the COVID-related reductions in global CO₂ emissions in road transportation (340.4 MtCO₂, -15.5% compared to 2019), power (292.5 MtCO₂, -6.4%), industry (136.2 MtCO₂, -4.4%), aviation (92.8 MtCO₂, -28.9%), residential (43.4 MtCO₂, 2.7%), and international shipping (35.9 MtCO₂, -15%) [8].

China is currently the largest energy consumer and CO₂ emitter in the world, accounting for approximately 30% of global emissions [9], therefore any significant changes happened in China will have a direct and significant influence worldwide. There has been some estimation on changes in China's energy consumption and CO₂ emissions due to the COVID-19. For instance, Han et al. used gross domestic product (GDP) and an inventory (China Emission Accounts and Datasets, CEADs) to estimate the decrease in CO₂ emissions in the first quarter of 2020 at national and regional levels, and implied that the lower coal consumption and cement output contribute largely to total CO₂ emission reductions [10]. Myllyvirta shows that China's carbon emissions fell by around 18% over a seven-week period compared with the same period last year [11].

These studies provide pioneering assessments of the extent of COVID-19 impacts on CO₂ emissions in 2020 and reached profound impacts on public and academia. However, few studies have provided a comprehensive and quantitative assessment to distinguish the decrease of energy-related CO₂ emissions due to COVID-19 from different sectors of China. Furthermore, estimation regarding the medium- and long-term impacts on CO₂ emissions derived from the stimulus policies issued by Chinese government to response this crisis is still lacking. In this study, we first estimate the CO₂ emission changes from electric power generation, coking, steel, methanol, transport, and construction specifically, and then use these results to estimate the decline of CO₂ emissions in the whole country. Furthermore, we analyze the medium- and long-term effects on CO₂ emissions of the stimulus packages in China.

China's energy use is mainly dominated by six energy-intensive industrial sectors and transport sector, whose CO₂ emissions accounted for 83.9% of China's total CO₂ emissions in 2017. Considering the availability of data, the degree of impact, and the proportion of CO₂ emissions for each sector, changes in energy-related CO₂ emissions were

estimated for these sectors and construction activity as well. According to the Statistical Report of National Economic and Social Development, the six energy-intensive industries are production and supply of electric power, petroleum processing and coking, raw chemical materials and chemical products, nonmetal mineral products, smelting and pressing of ferrous metals, and smelting and pressing of nonferrous metals, in which 62.5% of total CO₂ emissions came from the electricity and heat production, while the other five sectors covered 14.3%, and the transport contributed 7.1% of total CO₂ emissions. We collected time-series data representing changes in activity, such as coal demands in electric sector or operating rate of production, to estimate the percentage changes in CO₂ emissions instead of the absolute volume changes in CO₂ emissions in corresponding sectors.

The remaining paper is organized as follows. Sector 2 introduces the method and data for estimating CO₂ emission changes. Sector 3 reports the estimation results for six sectors and the whole country. The discussions regarding the medium- and long-term impacts and the policy implications are provided in Sector 4.

2. Method and data for estimating CO₂ emission changes

2.1. CO₂ emissions in 2019

The CO₂ emissions and sectoral structure data in 2017 are from CEADs. We assume that change rate of CO₂ emissions is equal to the annual growth rate in total energy consumptions (billion tons of standard coal equivalent) reported on the Statistical Communiqué [12,13]. Then the CO₂ emissions in 2019 for China can be estimated as follows:

$$\text{CO}_2 \text{ emissions}_{2019} = \text{CO}_2 \text{ emissions}_{2017} \times \text{AGR}_{2018} \times \text{AGR}_{2019} \quad (1)$$

where CO₂ emissions₂₀₁₉ and CO₂ emissions₂₀₁₇ indicate the total fossil fuel related CO₂ emissions of China in 2017 and 2019 respectively. AGR₂₀₁₈ and AGR₂₀₁₉ denote the annual growth rates in total energy consumptions of 2018 and 2019, respectively.

2.2. Change rate of CO₂ emission in industry sector

According to the proportion of CO₂ emissions in 2017, our estimations of change rate of CO₂ emissions in industrial sectors include electric power generation, coking, steel, and chemical. Following the method of Myllyvirta [11], we estimate the year-on-year change rates of CO₂ emissions in industry sectors using sector activity indicators: daily coal consumptions at power generation groups, operating rates in coking plant, blast furnace and steel plant, and oil refinery plant. The coal consumption and operating rate data were collected from WIND Information.

We use total coal consumptions at six major power generation groups to calculate the change rate of CO₂ emissions in electric power generation. Specifically, we assume the CO₂ emissions in electric power generation have a positive linear relationship with the total coal consumptions, thus the emission change rate in electric power generation is estimated as follows:

$$CR_E = \frac{\sum_i TCC_i \times CRTCC_i}{\sum_i TCC_i} \quad (2)$$

where CR_E refers to the change rate of CO₂ emissions in electric power generation, *i* indicates months - January, February and March - in the first quarter of 2020, TCC_{*i*} denotes the total coal consumptions at six major power generation in month *i*, CRTCC_{*i*} reflects the change rate of total coal consumptions in month *i* compared with the same period of last year.

We assume that the emission factors and the energy structure remain unchanged for each sector in 2020 compared with 2019. Hence, the change rate of the CO₂ emissions in coking, steel, and chemical can be estimated according to the change rate of operating rate in 2020

compared with the same period of 2019, as follows:

$$CR_I = \frac{\sum_i OR_i \times CROR_i}{\sum_i OR_i} \quad (3)$$

in which CR_I refers to the change rate of CO₂ emission in each sector of coking, steel, and chemical in the first quarter of 2020, OR_{*i*} represents the operating rate of corresponding sector in month *i*, CROR_{*i*} refers to the change rate of operating rate of corresponding sector in month *i*. In addition, we adopt their CO₂ emission proportions in 2017 as the weights to aggregate these change rates of CO₂ emissions into a single indicator of CO₂ emission change rate in industrial sector.

2.3. Change rate of CO₂ emissions in transport

For transport sector, in the absence of energy consumption related information, we assume the decrease of number of passengers sent by railway and civil aviation in the first quarter of 2020 year-on-year to be the decrease in CO₂ emissions of transport. The data were obtained from the Ministry of Transport of China. Thus, the change rates of CO₂ emissions in transport is calculated as follows:

$$CR_T = \frac{\sum_i NP_i \times CRNP_i}{\sum_i NP_i} \quad (4)$$

in which CR_T represents the change rates of CO₂ emissions in each sector of railway and civil aviation in the first quarter of 2020, NP_{*i*} indicates the number of passengers sent by corresponding sector in month *i*, CRNP_{*i*} denotes the change rates of corresponding number of passengers sent by railway or civil aviation in month *i* compared with the same period last year. The emission change rates of railway and civil aviation are aggregated into a single measure of change rate of CO₂ emissions in transport with the total energy consumptions of railway and civil aviation in 2018 as weights.

2.4. Change rate of CO₂ emissions in construction

The calculation of emission change rate for the construction is relatively straightforward. We assume that the change rate of CO₂ emissions in construction is equal to the change rate in cement output. We collected the monthly cement output data from National Bureau of Statistics [14] and estimate the year-on-year change rate of CO₂ emissions in construction as follows:

$$CR_C = \frac{\sum_i CO_i \times CRCO_i}{\sum_i CO_i} \quad (5)$$

in which CR_C is the change rate of CO₂ emissions in the first quarter of 2020 in construction, CO_{*i*} is the cement output in month *i* in 2020. CRCO_{*i*} is the change rate of cement output in month *i* of 2020 compared with the same period in 2019.

3. Results

3.1. CO₂ emissions from electric power generation would drop by 16%

As shown in Fig. 3 below, the daily total coal consumptions at six major power generation groups usually drop by an average of 50% in the 10 days commencing the Chinese New Year, and then rebound. However, in this year, in order to get the epidemic under control, the Chinese New Year holiday had been extended for 10 days (and even longer in some provinces) and many factories prolonged shutdown. In the 30 days period following the Chinese New Year, average daily coal consumption at power plants was still 30% lower than the same period of last year. According to the daily coal use data in the first quarter of this year, the CO₂ emissions from the electric power generation would drop by 16% over the first quarter of 2020 compared with the same period of last year.

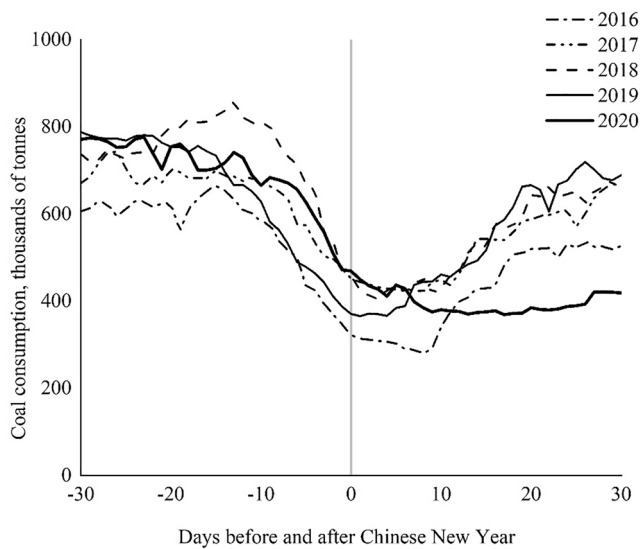


Fig. 3. Daily coal consumption at six major power generation groups. Daily total coal consumption around the Chinese New Year at six major power generation groups, in 1000 tonnes per day. Data Source: WIND Information.

3.2. CO₂ emissions from coking would reduce by 8%

As Fig. 4 shows, the operating rate of coking industry has decreased sharply after the Chinese New Year. Compared with the same period in 2019, at the end of this February, the operating rates of coking industries decreased by 30%, 21%, and 6% in the factories with production capacities less than 1 million tonnes, between 1 and 2 million tonnes, and greater than 2 million tonnes, respectively. This indicates that the CO₂ emissions of the coking industry in the first quarter would drop by approximately 8%.

3.3. CO₂ emissions from steel industry would reduce by 9.8%

Similarly, the indicators for steel industry capacity utilization

deteriorated further in 30 days after Chinese New Year (Fig. 5). In the first quarter of this year, compared with the same period in 2019, the operating rate for wire rod plant dropped by 10.6%; the reachability of design capacity for deformed steel bar plant dropped by 8.5%; and the operating rate for blast furnaces in February 2020 decreased by 4.3% compared with the same period in 2019. Therefore, the CO₂ emissions from steel industry would reduce by 9.8% in the first quarter of this year compared with the same period of last year.

3.4. CO₂ emissions from methanol would decrease by 1.6%

The operating rate for methanol production (Fig. 6), one of the representative operating rates for raw chemical materials and chemical products industry, dropped dramatically commencing the Chinese New Year. It typically kept stable or slightly increased during the holiday in the last few years. However, at the end of this February, the methanol's operating rate decreased by 7% compared with the same period in 2019. In the first quarter of 2020, the CO₂ emissions from raw chemical materials and chemical products industry would decrease by 1.6%.

3.5. CO₂ emissions from transport would decrease by 62%

By the end of this February, the number of passengers sent by railway and civil aviation within China decreased by 77.7% and 74.9%, respectively, compared with the same period in 2019, and remained at low levels commencing the Chinese New Year (Fig. 7). The suspensions and cancellations in trains, high-speed rails, and flights would lead to a reduction of 62% in CO₂ emissions in transportation in the first quarter of 2020 compared with the same period of 2019.

3.6. CO₂ emissions from construction would drop by 23.9%

The construction activity was affected as migrant workers who were not allowed to move or flow for weeks and couldn't return to cities after the Chinese New Year. In addition, insufficient supply of raw materials for the construction and stagnated investment in infrastructure has also caused some impacts in the short-term. The output in construction decreased by 17.5% in the first quarter [2], and, in consequence, the CO₂

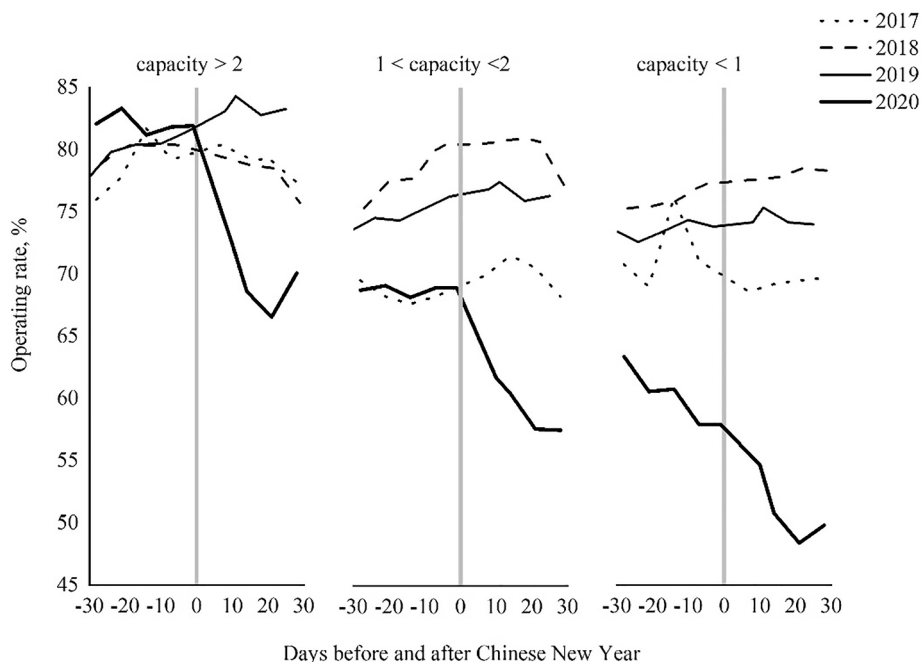


Fig. 4. Operating rate of coking industry. Operating rate of coking industry (%) around Chinese New Year. The units of capacity are 1,000,000 tonnes. Data resource: WIND Information.

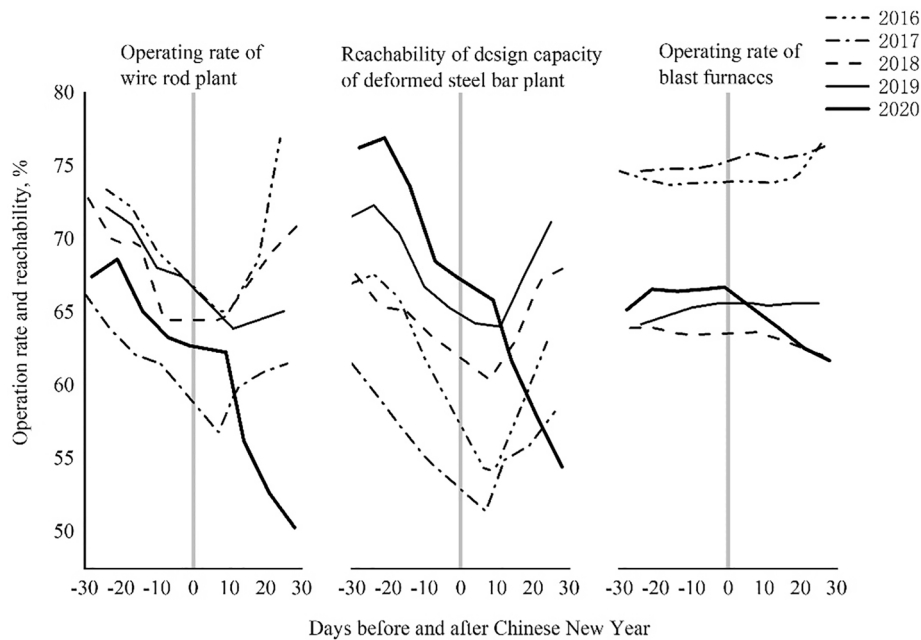


Fig. 5. Operation rate and reachability in steel industry. Operating rate for wire rod plant (%), reachability of design capacity for deformed steel bar plant (%), and operating rate for blast furnaces (%) around Chinese New Year. Data resource: WIND Information.

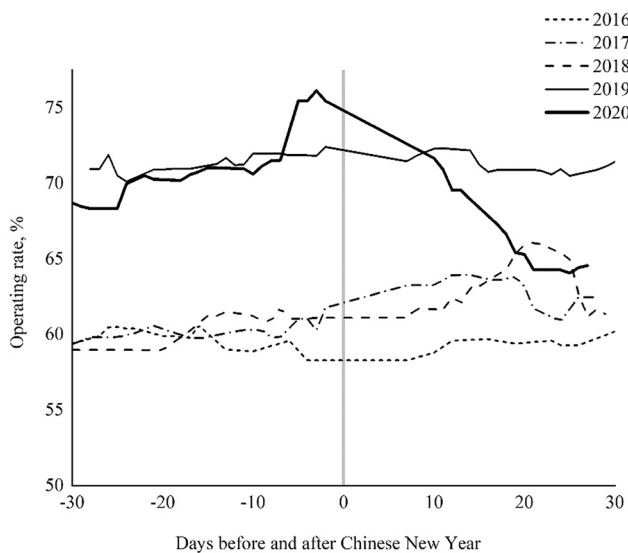


Fig. 6. Operating rate of methanol production. Operating rate of methanol production (%) around Chinese New Year. Data resource: WIND Information.

emissions from the construction would drop by 23.9% in the first quarter year-on-year.

3.7. China's total CO₂ emissions would reduce by 18.7% in the first quarter

To sum up, according to the estimations of the above-mentioned sectors, China's total CO₂ emissions would reduce by 18.7% (182.47 MtCO₂) in the first quarter of 2020 compared with the same period of 2019 due to the coronavirus pandemic. This is in line with the estimations of Le Quéré et al. [6] and Han et al. [10] The former took into account temporary reductions in daily global CO₂ emissions and reported that from the beginning of confinement to the end of April, the changes in CO₂ emissions were large with a decrease of 242 MtCO₂ in China. The latter used domestic economic data to assess the recent

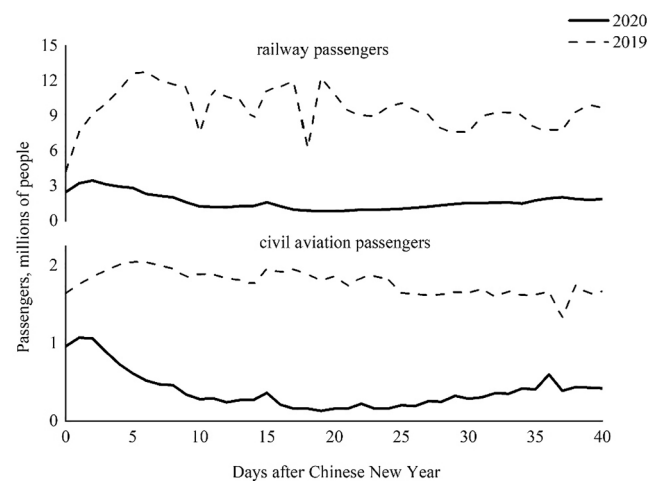


Fig. 7. Passengers sent by railway and civil aviation. Daily passengers sent by railway and civil aviation after the Chinese New Year, in 1,000,000 people per day. Data Source: WIND Information.

impact which shows that China's CO₂ emissions decreased by 257.7 MtCO₂ in the first quarter of 2020.

Although the first quarter impact of the current epidemic is large, with respect to CO₂ emissions, the annual figure would only reduce by around 1.6%. For comparison, Le Quéré et al. provided a projection of a reduction in emissions of 2.6% in 2020 in China with an assumption that the economic activities would recover to pre-crisis level in around mid-June [6], while the forecast of Myllyvirta showed a 1% reduction in CO₂ emissions in 2020 [11]. Han et al. reported that the decreases were estimated at 3.9% to 7.4% depending on the duration of this crisis [10].

Before the outbreak of the COVID-19, several organizations and researchers had predicted that China's energy consumptions and related CO₂ emissions would keep increase during 2020. In the latest outlooks of China's energy for 2040, the main prediction scenario of EIA is that the average annual growth rate of China's primary energy demand would be 0.8%, while the forecasts of Organization of the Petroleum Exporting

Countries and British Petroleum were more optimistic which are around 1.1% and 1.2% [15–17]. China National Petroleum Corporation expected average annual primary energy demand to grow by 2.4% between 2015 and 2020 and the country's CO₂ emissions to peak (10 GtCO₂) between 2025 and 2030 [18]. These forecasts, based on complex mathematical theories and a large amount of historical data, are considered with high reference value. They implied the energy consumptions and CO₂ emissions in China should have increased without this crisis. In other words, the COVID-19 has temporarily reduced the energy consumptions and related CO₂ emissions, but there is a great chance that the CO₂ emissions would rebound after the pandemic if there is no significant change on energy consumption structural or substantial improvement on energy use efficiency.

4. Discussion and conclusion

4.1. Stimulus packages may increase CO₂ with a higher speed in the coming years

We have seen reductions in CO₂ emissions in the first quarter, particularly in industry and transport. However, this reduction tends to be temporary, because this is the result of reduced economic activities instead of new development policies issued by the governments, structural changes in the economic systems, or improvement in energy efficiency. As stimulus packages – such as a policy loosening for allowing new coal plant to be established in February [19] – make economic activities back up, the CO₂ emissions would most likely increase with a higher speed in the coming years.

At the end of this March, China's central government emphasized again to achieve the economic and social development targets for the 13th Five-Year-Plan, including the goal of doubling GDP by the end of 2020 compared with the 2010's level. This goal would require an almost 6% GDP growth in 2020 [11]. Given the fact that China's preliminary accounting GDP dropped by 6.8% in the first quarter [2], stimulus packages for economic growth during the rest of the year would be most likely on the way.

There will be medium- and long-term consequences for energy consumptions and related CO₂ emissions from how countries boost their economies with short-term stimulus measures [20–22]. During previous economic crises, China tend to adopt stimulus packages including investments in “shovel-ready” infrastructure projects – establishing coal-fired power plants, building roads, railways, and airports, or investing in energy-intensive industries such as cement and steel – which definitely means more fossil CO₂ emissions. Back to the 2007–2010 period, for example, China's CO₂ emissions induced by capital formation grew rapidly as a result of stimulus spending that boosted fossil fuel use in the wake of the global financial crisis [23]. However, Chinese government tends to fall back on high-carbon projects to response this crisis. Lots of plans for building new coal-fired power plants in China, which have been put on ice in pursuit of renewable energy, could be revived rapidly if the focus is purely on economic growth [24]. Moreover, the investment scale of China's infrastructure is still a relatively large part of the country's overall investment. According to the disclosed specific investment plans of local governments in 2020, investment in infrastructure accounts for more than half of the total amount in some provinces.

Continuing the old way to respond to the COVID-19 disease may increase the CO₂ emissions in medium- and long-term. Furthermore, it has two additional limitations. First, it may counter to the government's goal about CO₂ emissions, such as to reduce CO₂ emissions per unit of industrial value added by 22% in 2020 compared with that in 2015. Second, it may miss the opportunity to develop low-carbon economy. A low-carbon economy is an economy based on low carbon power sources and needs to save energy and reduce greenhouse in order to keep sustainable economic and social development in the process of production and consumption [25]. In China, the cost of wind power is already lower than that of coal-fired power, and the cost of solar power is expected be

lower than that of coal-fired power as well by the end of this year [19]. In addition, the return from investment in oil and gas is very close to that from solar and wind projects nowadays [26]. Hence, it's a good opportunity to optimize the structure of energy systems (e.g. using clean energy to substitute for traditional fossil energy), which could both reduce the CO₂ emissions to accelerate China's climate goals and alleviate air pollution in China.

4.2. Sustainable stimulus packages will accelerate climate goals

The effects of coronavirus may be severe but likely to be temporary. However, the threat of climate change remains and will continue. The United Nations Environment Programme has pointed out that if we rely only on the current climate commitments of the Paris Agreement, global temperature is expected to rise by 3.2 °C at the end of this century. Collectively, we must deliver an annual decrease of 7.6% greenhouse gas emissions between 2020 and 2030 if we want to limit global warming to 1.5 °C [27]. We should not allow today's crisis to compromise the efforts to tackle the world's inescapable challenge of climate change. In addition, China had made a great progress in adjusting its energy structure. In 2019, China's coal consumptions decreased by 1.5% compared with last year. The consumptions of natural gas, hydropower, nuclear power, wind power, and other clean energy increased by 1.3%, which accounted for 23.4% of the total energy consumptions; Meanwhile, the consumptions of non-fossil energy also increased by 0.8% and accounted for 14.9% of total primary energy consumptions [12]. We should be careful to response this crisis and develop economic with no harm to both climate goals and our progress in energy structure transition.

The good news is researches already showed that a better economic growth and a better climate can be obtained simultaneously, which means economic development and CO₂ emissions reductions can be coordinated [28,29]. Moreover, there are evidences that global economic growth and fossil fuel related CO₂ emissions may have begun to decouple. In 2014, the global economy increased by about 3%, but energy-related CO₂ emissions remained stable [30]. Governments can use the current situation to accelerate the climate goals and launch sustainable stimulus packages focused on building a secure, clean and sustainable energy future, such as large-scale investment to boost the research and development of clean energy, advanced batteries, and energy efficiency technologies, to avoid increase too much CO₂ emissions.

Specifically, for China, the country can invest the construction of “New Infrastructure” projects such as 5G networks, industrial internet, inner-city transportation and inner-city rail systems, ultra-high voltage power transmission projects, and new energy vehicle charging stations. These projects can not only create a considerable amount of new jobs to grow our economics but emit less CO₂. Second, the government should insist to transition its economy from a high energy-consumption model to a low-carbon one, which is an irreversible trend and its future benefits and positive influence on other sectors could be huge. Third, government and enterprises can enlarge the proportion of investments in the research and development of new technologies to improve energy efficiency.

Affected by the coronavirus pandemic, China's CO₂ emissions would decrease in the short-term. However, the medium- and long-term effects on CO₂ emissions are uncertain and the government should respond the crisis carefully to avoid extra CO₂ emissions growth. The extent to which the central and local governments consider the CO₂ emissions targets and the imperatives of climate change when carrying out their economic stimulus to the epidemic may affect the pathway of CO₂ emissions for decades.

CRedit authorship contribution statement

Qingqing Wang: Methodology, Investigation, Writing - original draft. **Mei Lu:** Methodology, Formal analysis, Visualization. **Zimeng**

Bai: Resources, Investigation, Visualization. **Ke Wang:** Conceptualization, Investigation, Writing - review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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