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A preliminary assessment of the impact of COVID-19 on environment – A case study of China

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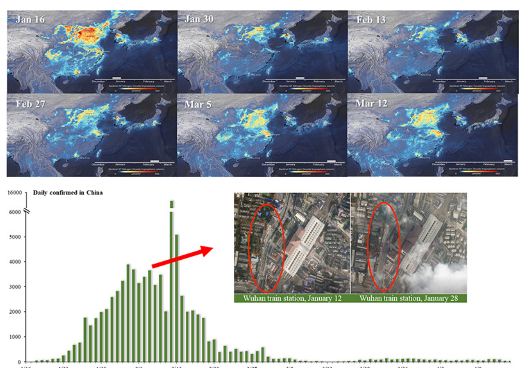
HIGHLIGHTS

- COVID-19 improved China's air quality in the short term.
- Satellite data show a sharply decline in NO_2, an indicator for environment.
- Declining economic activities leads to reduction in energy consumption and NO_2 emissions.
- Strict quarantine measures benefit to the environment.

GRAPHICAL ABSTRACT



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ABSTRACT

The coronavirus disease (COVID-19) is seriously threatening world public health security. Currently, >200 countries and regions have been affected by the epidemic, with the number of infections and deaths still increasing. As an extreme event, the outbreak of COVID-19 has greatly damaged the global economic growth and caused a certain impact on the environment. This paper takes China as a case study, comprehensively evaluating the dynamic impact of COVID-19 on the environment. The analysis results indicate that the outbreak of COVID-19 improves China's air quality in the short term and significantly contributes to global carbon emission reduction. However, in the long run, there is no evidence that this improvement will continue. When China completely lifts the lockdown and resumes large-scale industrial production, its energy use and greenhouse gas (GHG) emissions are likely to exceed the level before the event. Moreover, COVID-19 significantly reduces the concentration of nitrogen dioxide (NO_2) in the atmosphere. The decline initially occurred near Wuhan and eventually spread to the whole country. The above phenomenon shows that the decreasing economic activities and traffic restrictions directly lead to the changes of China's energy consumption and further prevent the environment from pollution. The results in this study support the fact that strict quarantine measures can not only protect the public from COVID-19, but also exert a positive impact on the environment. These findings can provide a reference for other countries to assess the influence of COVID-19 on the environment.

1. Introduction

The emergence of the coronavirus disease 2019 (COVID-19) has brought great challenges to world public health security (Wang et al.,

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2020). On March 11, the World Health Organization (WHO) announced that the COVID-19 has constituted a "global pandemic" and called for an aggressive global response. According to statistics, as of April 16, 2020, the cumulative number of confirmed cases of COVID-19 has exceeded 1.99 million, and >200 countries and regions have been affected by the epidemic (World Health Organization, 2020c).

The global outbreak and spread of COVID-19 not only seriously threatens public health (Bai et al., 2020; Sohrabi et al., 2020), but also greatly hinders global economic growth (Lai et al., 2020). Gita Gopinath from the International Monetary Fund (IMF) pointed out that due to the impact of the COVID-19, the global economy would experience a recession in 2020, and the economic growth rate would drop to −3% (Gopinath, 2020). This result is 6.3% lower than the forecast in the World Economic Outlook released by the IMF in January 2020. The COVID-19 is considered to negatively affect the world economy due to two main reasons. First, the rapid spread of the epidemic worldwide has directly led to a sharp increase in the uncertainty of economic development, which has triggered turbulence in financial and capital markets (McKibbin and Fernando, 2020). Secondly, in order to control the spread of the epidemic, countries have strictly restricted the movement of people and transportation, and economic activities have been greatly reduced (Fernandes, 2020), which puts pressure on economic operations from both consumption and production sides. Many scholars forecast that the effect of the COVID-19 on the economy will outweigh that of the 2008 financial crisis.

Existing research shows that pollution will increase with economic growth and decrease with economic decline (Raupach et al., 2007; Wang and Su, 2020; Wang et al., 2019). Since COVID-19 leads to economic downturn, will it also bring down the pollution? For the purpose of systematically evaluating the dynamic impact of the COVID-19 on the environment, this paper takes China as a case study and conduct an in-depth discussion on the changes of major environmental pollutant emissions during the period from outbreak, spread to basic control of the COVID-19. This study not only provides a theoretical reference for other countries to assess the impact of COVID-19 on the environment, but also enriches the theoretical research on the relationship between economy and pollution from an emergency-economy-environment perspective.

2. Background information: coronavirus disease in China

At the end of December 2019, there were cases of pneumonia caused by coronavirus in Wuhan, Hubei Province, China. Subsequently, the coronavirus was officially named coronavirus disease 2019 (COVID-19) by the WHO, and quickly spread to other parts of Hubei Province and nationwide (World Health Organization, 2020b). From January 16 to 24, the number of confirmed cases per day increased rapidly. This may be related to Chinese New Year. Since January 16th, a large-scale population migration across the country to celebrate the New Year, accelerated the spread of the COVID-19 to a certain extent. Fig. 1 summarizes the daily confirmed cases from January 16 to April 15 in 2020.

According to the data in Fig. 1, up to now, the spread of COVID-19 in China has been basically controlled. On February 12, the number of reported COVID-19 cases in China reached its peak, with about 15,153 new cases on the same day. From January 23 to February 4, China's daily reported cases has accelerated, which means that the population infected with COVID-19 further expanded. From February 5th to 11th, the number of confirmed cases per day has decreased, indicating that the quarantine measures are effective in suppressing the spread of the virus. Moreover, China extended the Spring Festival holiday, which results in the population mobility during the Spring Festival in 2020 being much lower than that during the Spring Festival in 2019 (Hu, 2019). After February 12, the number of daily confirmed cases gradually declined and eased. Especially after February 14, in addition to Hubei Province, the number of new confirmed cases in other regions of China has been steadily decreasing, and the number of new patients per day has fallen to the level of a single digit.

3. Investigating the effects of coronavirus on air pollution

3.1. Decline in economic activity and energy consumption

In order to suppress the COVID-19, China issued a travel restriction order. Nearly half of China's population (over 780 million people) live in various forms of travel restrictions (Griffiths and Woodyatt, 2020). The residential areas of the cities and provinces most affected by the outbreak are completely closed, and no one can enter or leave. Chinese provincial governments announced strict restrictions on movement, from checkpoints at building entrances to outdoor activities. These measures include traffic restrictions on all non-emergency vehicles and the closure of all non-essential public places. Residents of every city only get the necessities of life from the neighborhood committee and community committee, because of the policy of quarantine. Many cities closed train stations to prevent people from entering the city unless they are proved live or work there. In the countryside, villages are separated by vehicles, tents and other temporary barriers. In terms of economy, a large number of enterprises stopped production. Business leaders stated that unless the permission of the local epidemic prevention department is obtained, the company shall not resume production (World Health Organization, 2020a).

In Wuhan, the quarantine measures were implemented on January 23, 2020 to interrupt the spread of the epidemic. Furthermore, Wuhan's

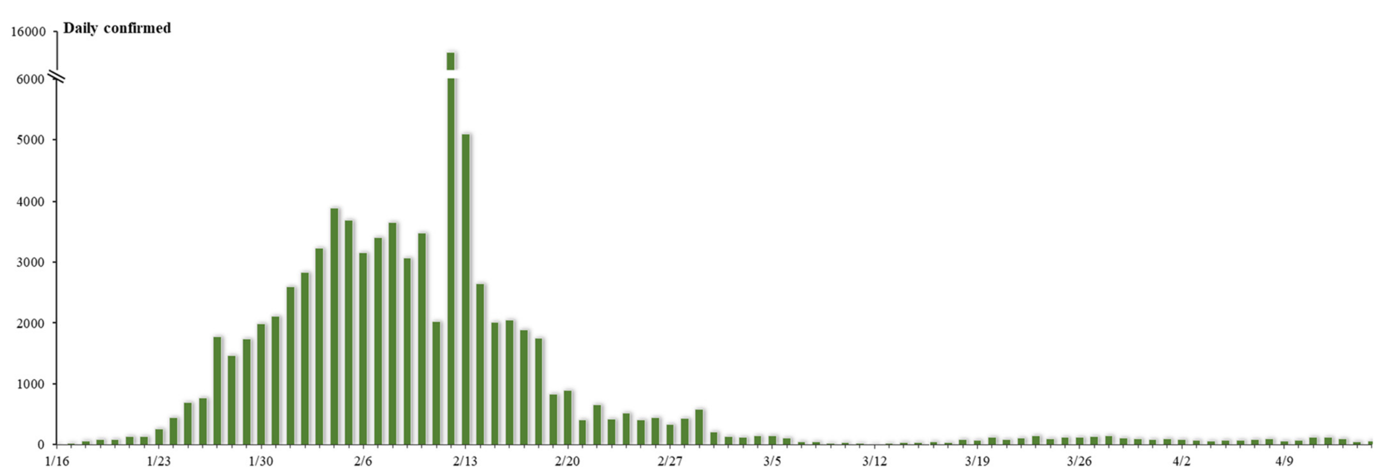

Fig. 1. Daily Changes in new confirmed cases of COVID-19 in China.
Source: (Chinese Center for Disease Control and Prevention, 2020).

transportation and local businesses were shut down to avoid the spread of the disease. Satellite images from Planet Labs of NASA captured scenes of traffic and parking lots near Wuhan Railway Station before and after the lockdown (January 12 and January 28, 2020), as shown in Fig. 2 (NASA, 2020b). The Wuhan Yangtze River Bridge is an important transportation hub in Wuhan, and the road became empty after the government imposed a lockdown in Wuhan (Fig. 3). In the next two weeks, >80 cities in China from 15 provinces (including municipalities and autonomous regions) were placed on lockdown, and implemented closed management of urban residential areas. Studies show that the issuance of traveling restrictions is an effective way to stop the spread of the epidemic. This measure delayed the overall outbreak progress in mainland China by 3 to 5 days (Chinazzi et al., 2020).

Due to the substantial reduction in urban transportation and industrial activities, China's energy consumption decreased significantly during the quarantine period. China is a large coal consumer, and the coal resource dominates the energy consumption structure. From the observed data in Fig. 4, China's coal consumption declined during the epidemic. In most cases, China shuts down for one week during the Lunar New Year every winter, and a large proportion of industries stop operating. This holiday usually causes a brief reduction in energy consumption. In the days after the Spring Festival, energy consumption will rise again with the resumption of production.

The Spring Festival in 2020 seems to be an exception, due to the large-scale outbreak of COVID-19. Compared with the same period in previous years, coal consumption dropped significantly. After the Spring Festival in 2020, the decline in coal use was extended for 20 days, with no sign of a rebound. This is because the government adopted strict restrictions to extend the annual leave, aiming to control the COVID-19 and prevent its further spread. And after officially resuming work on February 10, coal consumption demand is still sluggish.

China has experienced the peak of the epidemic and is now gradually recovering. On April 18, the National Bureau of Statistics of China released its preliminary accounting results of GDP in the first quarter of 2020. Affected by the coronavirus disease, China's GDP in the first quarter was 20.65 trillion yuan, showing a negative economic growth, a decrease of 5.3% over the same period last year (National Bureau of Statistics of China, 2020b). Among them, the added value of the first industry was 1018.6 billion yuan, decreased by 3.2%; the added value of the second industry was 7363.8 billion yuan, decreased by 9.6%; the added value of the tertiary industry was 12,268 billion yuan, decreased by 5.2%. Fig. 5 presents the quarterly GDP growth curve from 2016 to 2020. Overall, China's economic growth has maintained a long-term trend since 2016. However, the outbreak of COVID-19 exerted a certain negative impact on the economy this year. During the quarantine period, household consumption was suppressed, making that the three major demands (final consumption expenditure, total capital formation, and net exports of goods and services) all declined to varying degrees, driving negative economic growth (Zhao, 2020b).

In fact, China's domestic consumer market has huge potential for demand, and it has maintained a stable and upward trend for a long time. Moreover, the recovery trend is emerging in March (Zhao, 2020a). After entering March, the resumption of production accelerated step by step, the transportation logistics gradually recovered, and the country took strong measures to stabilize prices and ensure supply. According to statistics, although China's industrial production declined during the epidemic, the basic raw material industry and high-tech manufacturing industry maintained a slow growth (Dong, 2020). In the first quarter, the added value of industries above designated size fell by 8.4% year-on-year. Specifically, the value added of industrial enterprises above designated size in March decreased by 1.1% year-on-year, a decrease of 12.4 percentage points from January to February, indicating that the scale of industrial output is close to the level of the same period last year. On the other hand, restricted travel prevented people from going to shopping malls and reduced market sales, but the sales of necessities and physical goods on the Internet have increased rapidly (National Bureau of Statistics of China, 2020a). In terms of investment, investors' confidence is increasing, and thus investment in e-commerce, professional technical services and anti-epidemic related industries grows significantly.

During the quarantine period, the operating level of China's major industries was much lower than normal. A series of other industrial indicators are used to illustrate the changes in China's industrial activities and energy consumption during the epidemic (Fig. 6). Fig. 6a shows Qinhuangdao's coal throughput, which is one of China 's important coal ports. The number fell to its lowest level in four years in four weeks in February. Similarly, the refinery operating rate in Shandong Province, China's main refining center, has fallen to its lowest level since autumn 2015 (Fig. 6d), indicating a sharp decline in oil demand prospects. The average coal consumption of power plants reached its lowest level in four years. In addition, due to the slowdown in economic growth, China's industrial production activities have a potential decline in the potential demand for petroleum products, steel and other metals far greater than production, resulting in a record high inventory level, which will put pressure on future production.

Taken together, the use of coal and crude oil decreased during the lockdown in China. Compared with the same period after the Spring Festival holiday in 2019 (within the same two weeks), CO_2 emissions reduced by 25% or more. The above data means that China has reduced about 1 million tons of carbon emissions, equivalent to 6% of global emissions over the same period. This decline coincided with the lockdown during the epidemic. It can be concluded that COVID-19 exerted

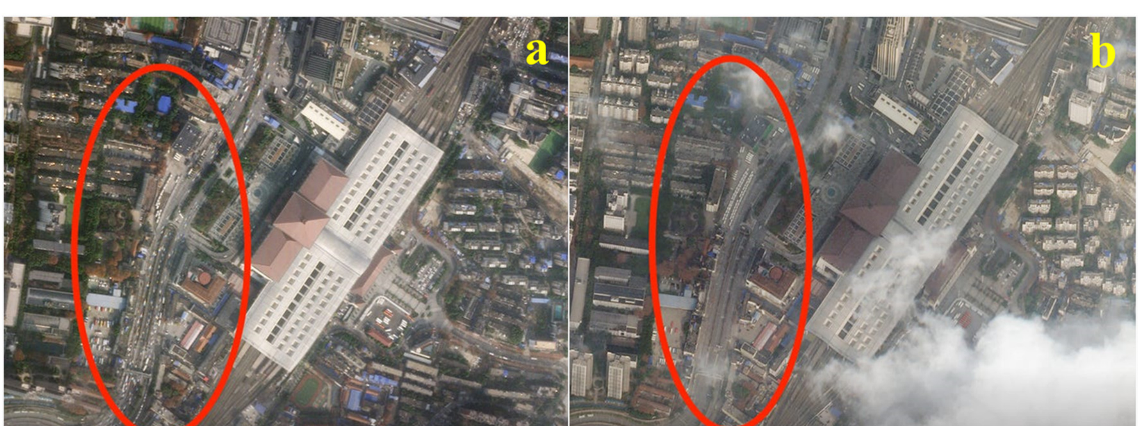

Fig. 2. Wuhan train station before and after the quarantine.
Source: (Pasley and Frias, 2020).

Fig. 3. Wuhan Yangtze River Bridge before and after the quarantine.
Source: (Pasley and Frias, 2020).

a significant negative impact on China's energy consumption and GHG emissions in the short term.

3.2. Changes in environmental indicator - nitrogen dioxide emissions

NO_2 received extensive attention from the international community as an important indicator of environmental pollution. Both the NASA and the ESA have tracked and reported the concentration of NO_2 in the atmosphere. Their satellites detected that the NO_2 in the air across China decreased significantly, which is partly related to the COVID-19.

3.2.1. Nitrogen dioxide measurement

3.2.1.1. Nitrogen dioxide — environmental indicator. Studies show that coal produces large amounts of air pollutants during the combustion process, including CO_x, SO_x, NO_x, particulate matter (PM) and heavy metals (Munawer, 2018). The accumulation of these pollutants in the air and water can cause serious environmental pollution. For example, the high concentration of NO_x in the atmosphere will cause nutrient pollution in coastal waters and also cause smog. NO and NO_2 react with other chemicals and form acid rain, which harms the ecosystem (Akimoto, 2003). Nitrogen dioxide (NO_2) is regarded as an indicator of nitrogen oxides and is used to assess environmental pollution levels. The WHO lists NO_2 as one of six typical air pollutants (Brunekreef and Holgate, 2002).

NO_2 is harmful to human health. It is a reddish-brown irritating gas, which is reddish brown gas or yellowish-brown liquid when cooled or compressed. Breathing air containing high concentrations of NO_2 will stimulate the body's respiratory system, this toxic gas will corrode the body's lung tissue. Short-term exposure to high concentrations of NO_2 can cause respiratory symptoms (such as coughing, wheezing, or difficulty breathing) and aggravate respiratory diseases. NO_2 mainly comes from the combustion of oil, coal, natural gas and other fuels and the exhaust of urban vehicles. It is estimated that anthropogenic

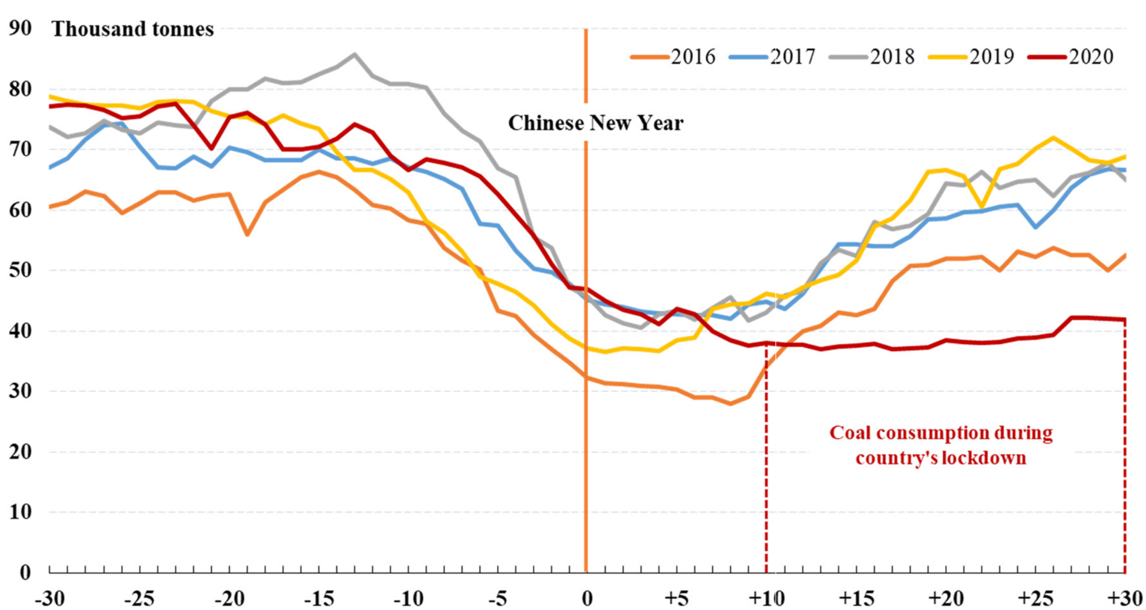

Fig. 4. Coal consumption in China during the COVID-19.
Source: (Ghosh, 2020).

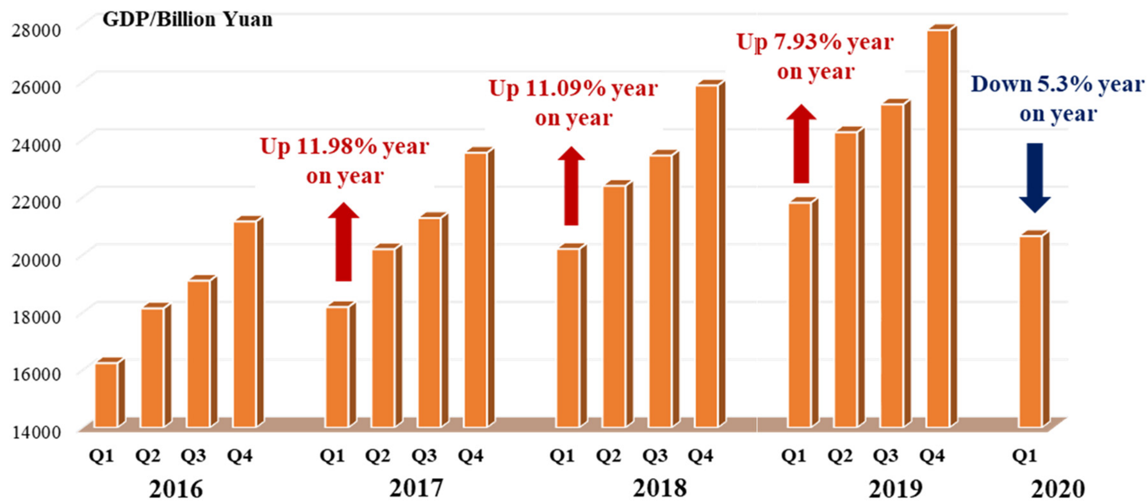

Fig. 5. Quarterly GDP growth 2016–2020.
Source: National Bureau of Statistics of China.

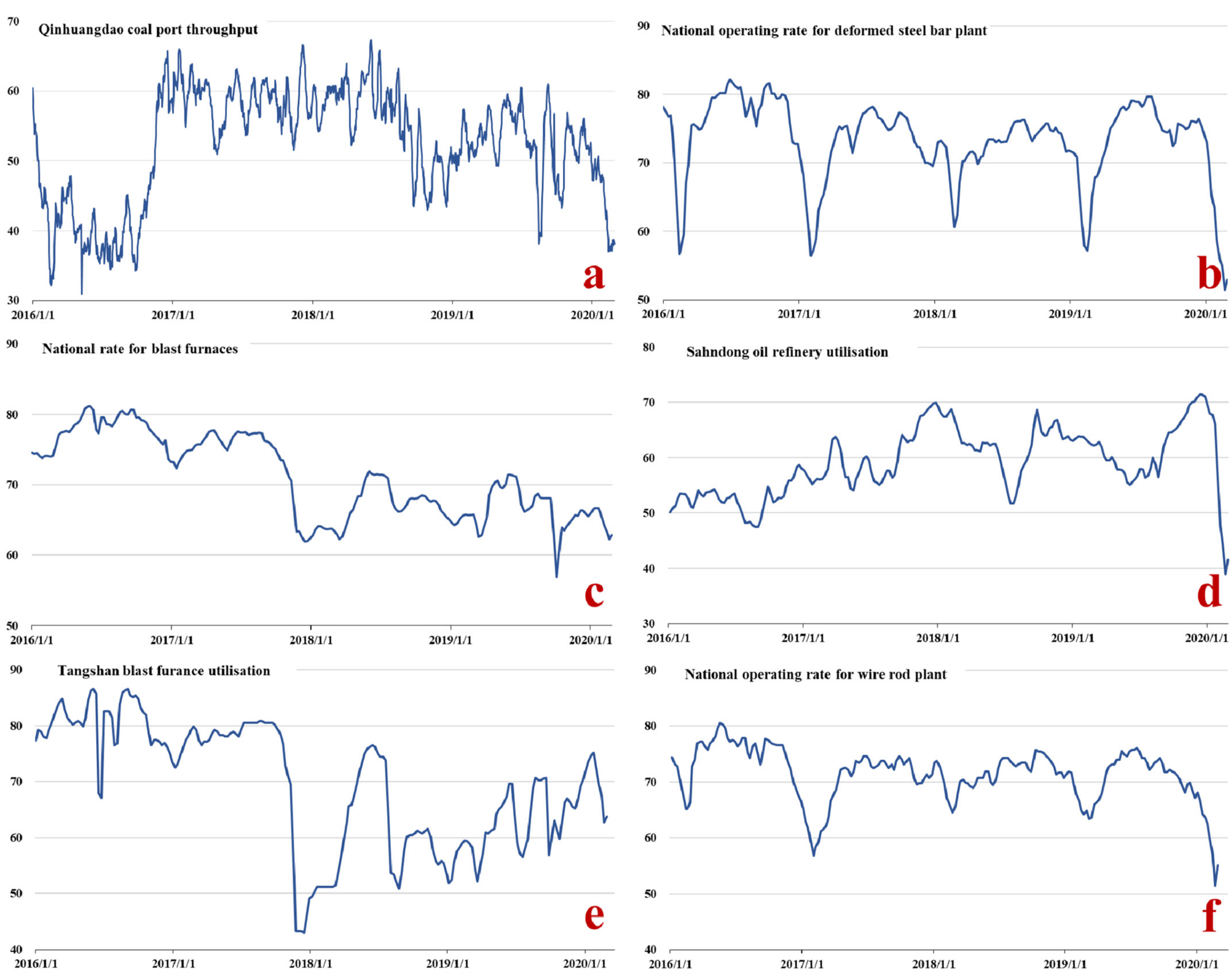

Fig. 6. Indicators of industrial activity in China (14-day average utilization, percent).
Source: (Myllyvirta, 2020).

pollution worldwide emits approximately 53 million tons of nitrogen oxides per year. Therefore, in order to scientifically assess whether the COVID-19 outbreak has an adverse impact on the environment, this study uses the concentration of NO_2 in the air as an evaluation indicator.

3.2.1.2. Precise monitoring of satellite. The National Aeronautics and Space Administration (NASA) is an administrative scientific research agency of the United States Federal Government, which is responsible for formulating and implementing the US space program and carrying out research in space science. NASA used the ozone monitoring instrument (OMI) on the launched Aura satellite to collect the changes in China's NO_2 emissions before and after the outbreak of the COVID-19.

The European Space Agency (ESA) is an intergovernmental organization composed of 22 European countries dedicated to exploring international space, with its headquarters in Paris, France. ESA uses Copernicus Sentinel-5P satellite to track and observe air pollution in the atmosphere. Copernicus Sentinel-5P troposphere monitor (Tropomi) and other instruments can not only measure the content of the compounds, but also measure the content of ozone, sulfur dioxide, carbon monoxide and methane.

3.2.2. Nitrogen dioxide over China

The tropospheric monitor on the Sentinel-5 satellite of ESA collected data on the NO_2 in the troposphere across China from December 19, 2019 to March 15, 2020. In Fig. 7, the darker the color on the map, the higher the pollutant content. Taking January 23 as the basis for time division, because Wuhan implemented the lockdown on this day, this study shows the changes in the amount of nitrogen dioxide in the atmosphere before and after the lockdown of the city (on a weekly cycle). Overall, the NO_2 in China was significantly lower in February than in the previous period.

The week before Wuhan announced the lockdown on January 16, the concentration of NO_2 in North China and Northeast China was at a relatively high level. These areas are heavy industrial areas of the country, and intensive industrial production activities emit large amounts of greenhouse gases and air pollutants. On January 30, within a week of the lockdown in Wuhan, nationwide NO_2 emissions were significantly reduced. This was attributed to a number of other cities adopting lockdown measures and more businesses and factories shutting down to avoid gathering and prevent the spread of COVID-19. Industrial production activities, the main source of NO_2, decreased and then air quality improved accordingly.

As the epidemic gradually under control, the Chinese government announced that industrial enterprises would resume production from February 10. In contrast, since the end of February, the concentration of pollutants in various regions of China has increased to a certain extent, because factories have resumed production. Therefore, during the quarantine period, the COVID-19 did make an important contribution to improving China's air quality. However, this contribution is only temporary. Once the industrial production is resumed, the amount of NO_2 emissions will rebound, which is not what we expected.

3.2.3. Nitrogen dioxide emissions in Wuhan, Nanjing, Shanghai

Generally speaking, the reduction of NO_2 emissions in China is related to the Spring Festival, because the factories are closed during that period. Past observations showed that air pollution usually decreases during this time. Once the Spring Festival ends, the pollution concentration will rise. However, the sudden drop of NO_2 emissions in China's air in early 2020 is not only caused by holiday effects or weather changes. The TROPOMI sensor on the Sentinel-5 Precursor platform measures the composition of the global atmosphere every day with unprecedented spatial resolution. In the preliminary analysis, NASA researchers compared the 2020 NO_2 value measured by OMI with the average value for the same period in 2005–2019. The results indicate that the NO_2 emissions in eastern and central China is significantly lower than the normal level during the same period. In addition, satellite monitoring instruments provide important information about air quality in Chinese cities (Wuhan, Shanghai and Nanjing). Fig. 8

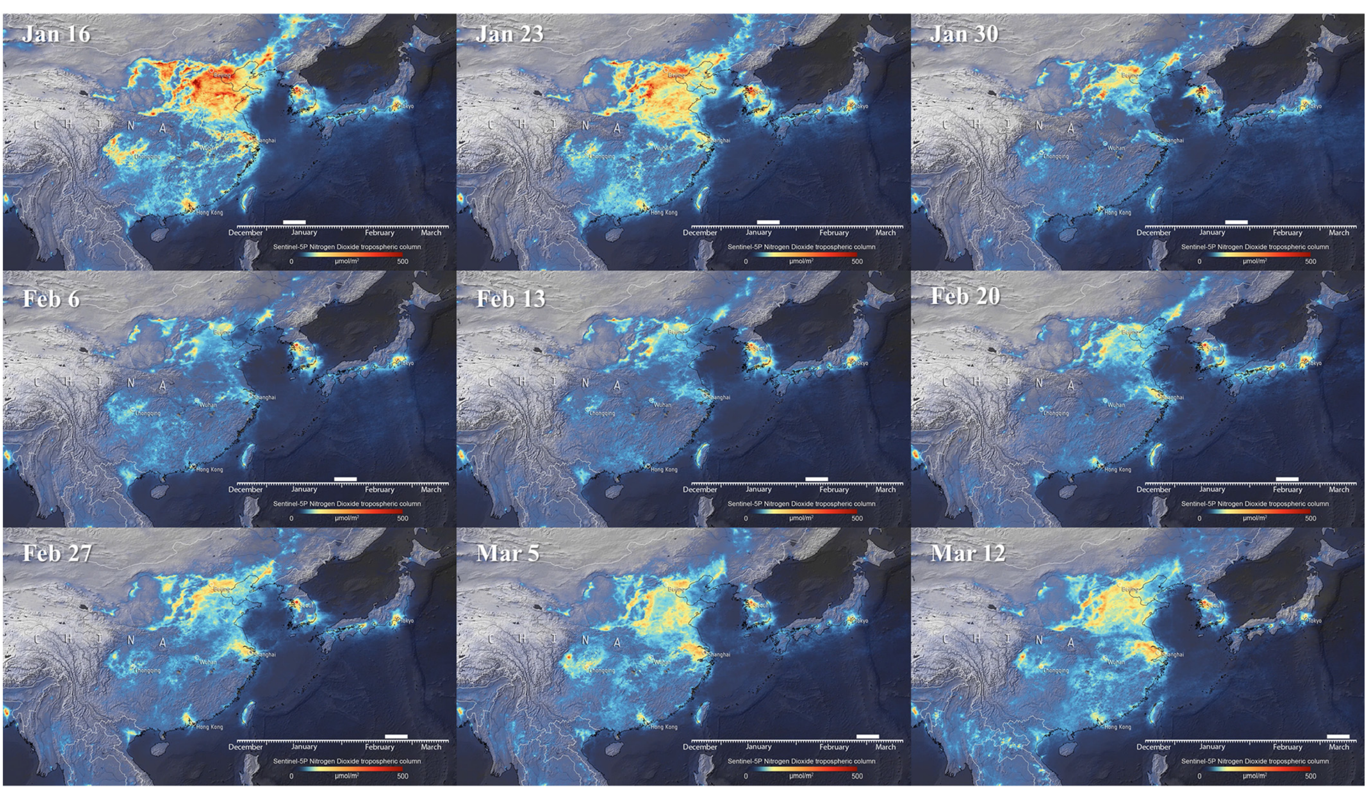

Fig. 7. Changes in nitrogen dioxide emission levels in China.
Source (European Space Agency, 2020).

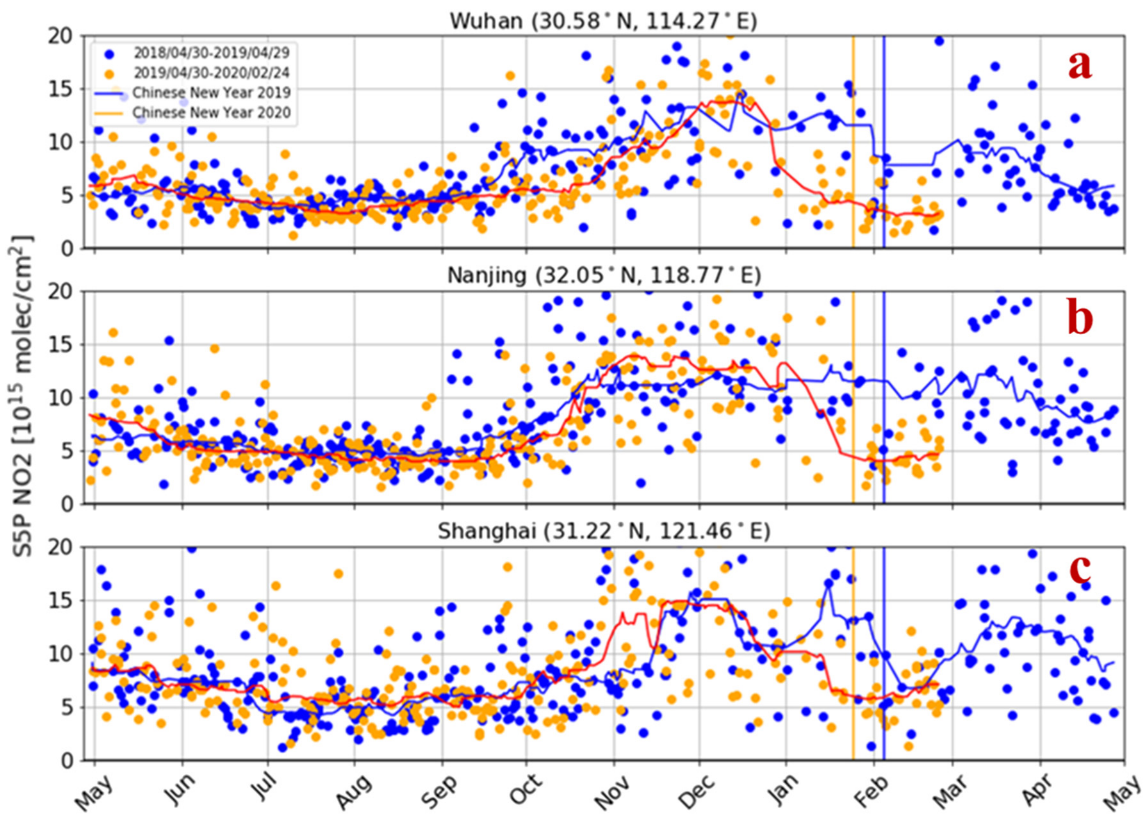

Fig. 8. Changes in NO_2 emission in Wuhan, Nanjing, Shanghai.
Source: (Royal Belgian Institute for Space Aeronomy, 2020).

illustrates time series of tropospheric NO_2 above three cities over a 2-year period.

The NO_2 concentration in the troposphere over Wuhan and Nanjing shows that the concentration as of the end of 2019 (at the time of the first COVID-19 case report) is still the same as in 2018. Around the Chinese New Year last year, the concentration of NO_2 over Wuhan began to decline. However, the concentration of NO_2 over Wuhan this year has fallen at a very rapid rate before the Chinese New Year, and the minimum standard finally reached has been reduced by about 50% compared with last year. At the same time, Wuhan reported the emergence of COVID-19. Normal production activities usually resume within 1 to 2 weeks after the Spring Festival, and the concentration is slowly returning to normal levels. But concentration in this year has been low, at least within a month after the Spring Festival, which is because of the lockdown and other measures taken to reduce the spread of COVID-19. The impact of COVID-19 on tropospheric NO_2 emissions is not limited to these big cities, but can be seen all over China. In the week following the long holiday of the Spring Festival in 2020, the average level in other parts of China is >30% lower than the same period in 2019.

In order to prevent and control the spread of the COVID-19 nationwide, local governments adopted measures such as outdoor restrictions, closed management and traveling restrictions. Fig. 9 shows the average concentration of NO_2 in the atmosphere measured by the ozone monitor (OMI) on NASA's Aura satellite. The map in Fig. 9 shows the NO_2 values of Wuhan in three periods in 2020: January 1–20 (before Chinese New Year), January 28–February 9 (after the New Year) and February 10–25th (during the New Year celebration), and the comparison with the same period in 2019 for reference. Compared with the same period last year, the NO_2 emissions was significantly reduced. At the same time, the declining NO_2 emissions has not recovered since the end of the Spring Festival. NASA said that the reduction in NO_2 pollution initially appeared near Wuhan and eventually spread throughout the country.

NO_2 in the troposphere is an important indicator of air pollution. Observing changes in the content of NO_2 in the atmosphere can accurately capture the improvement in air quality (NASA Earth Observatory, 2016). The monitoring results show that the COVID-19 seriously threatens public health, but its short-term contribution to reducing emissions is significant. This is because China adopted strict restrictions when fighting against the COVID-19, with the entire country shutting down. These restrictions not only slowed down domestic economic growth, but also effectively reduced GHG emissions. But this decline is only short-term, and in the long run, a rebound is inevitable. Hence, how to take into account the environment protection while restoring the economy is an issue that policymakers should fully consider when making decisions.

3.3. Changes in other key air pollutant

There is evidence that air quality in most regions of China has improved significantly during the epidemic. The Ministry of Ecology and Environment of China monitored and evaluated air pollutants in 337 major cities across the country. They released the national report on surface water and ambient air quality for the past three months.

Fig. 10 shows the air quality assessment results of these cities in the first quarter. From January to March, the average air quality ratio of these 337 prefecture-level and above cities was 83.5%, an increase of 6.6 percentage points year-on-year. In addition, the ambient air quality of 120 cities reached the standard, an increase of 24 year-on-year. More concretely, the proportion of Beijing's excellent days in March was 90.3%, up 19.3 percentage points year-on-year; the average ratio of excellent days in March for 41 cities in the Yangtze River Delta region was 96.8%, up 12.6 percentage points year-on-year.

Fig. 11 lists the emissions of six typical air pollutants during the epidemic situation. It can be seen from the figure that the emissions of five kinds of air pollutants have declined, indicating that the air quality is

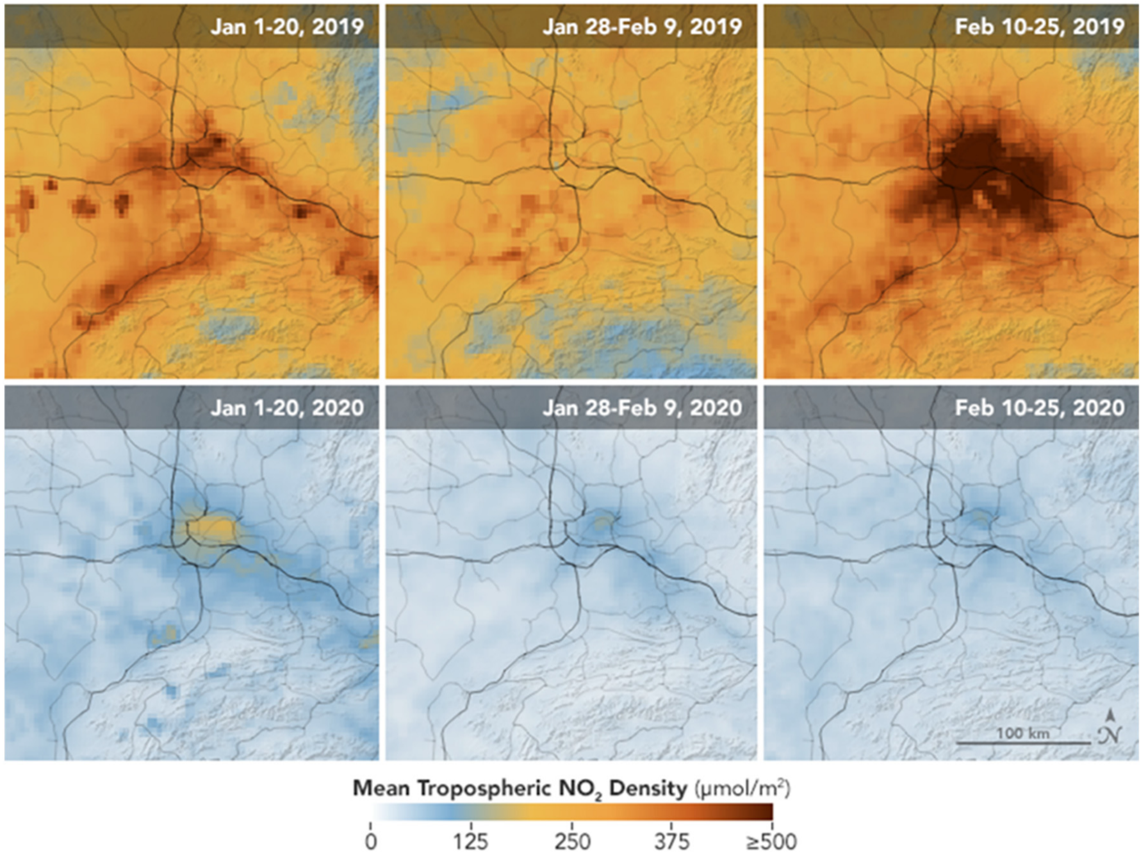

Fig. 9. Changes in NO_2 emissions in Wuhan, China.
(Source: (NASA, 2020a).

gradually improving. Among them, $PM_{2.5}$ concentration was 46 μg/m^3, down 14.8% year-on-year; NO_2 concentration of 24 μg/m^3, a year-on-year decrease of 25%; CO concentration of 1.5 mg/m^3, a year-on-year decrease of 6.2%, PM_{10} concentration was 66 mg/m^3, down 20.5% year-on-year; SO_2 concentration was 11 μg/m^3, down 21.4% year-on-year; O_3 concentration was 105 μg/m^3, which was flat year-on-year.

4. Conclusion

This study comprehensively discussed the short-term impact of the COVID-19 on the Chinese environment from the perspective of time and space. The main conclusions of this paper are as follows.

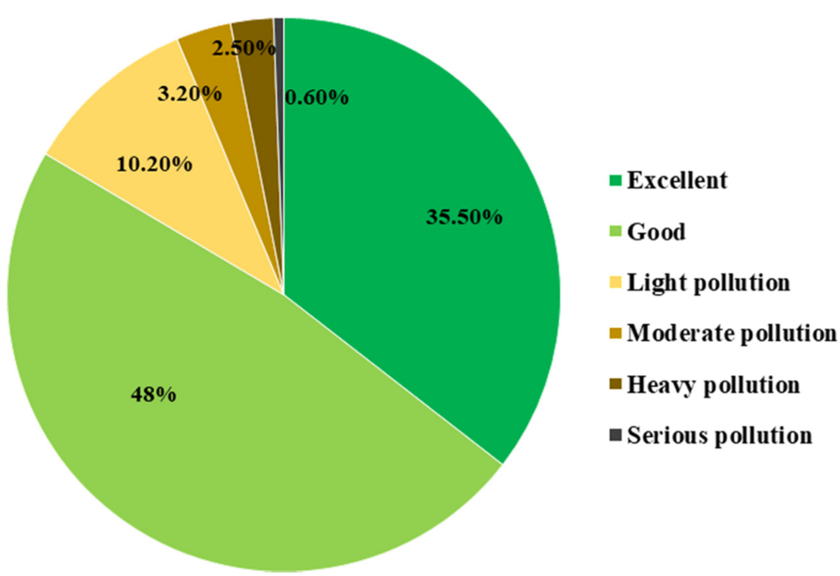

Fig. 10. Air quality of 337 cities nationwide in the first quarter of 2020.
Source: (Ministry of Ecology and Environment of China, 2020).

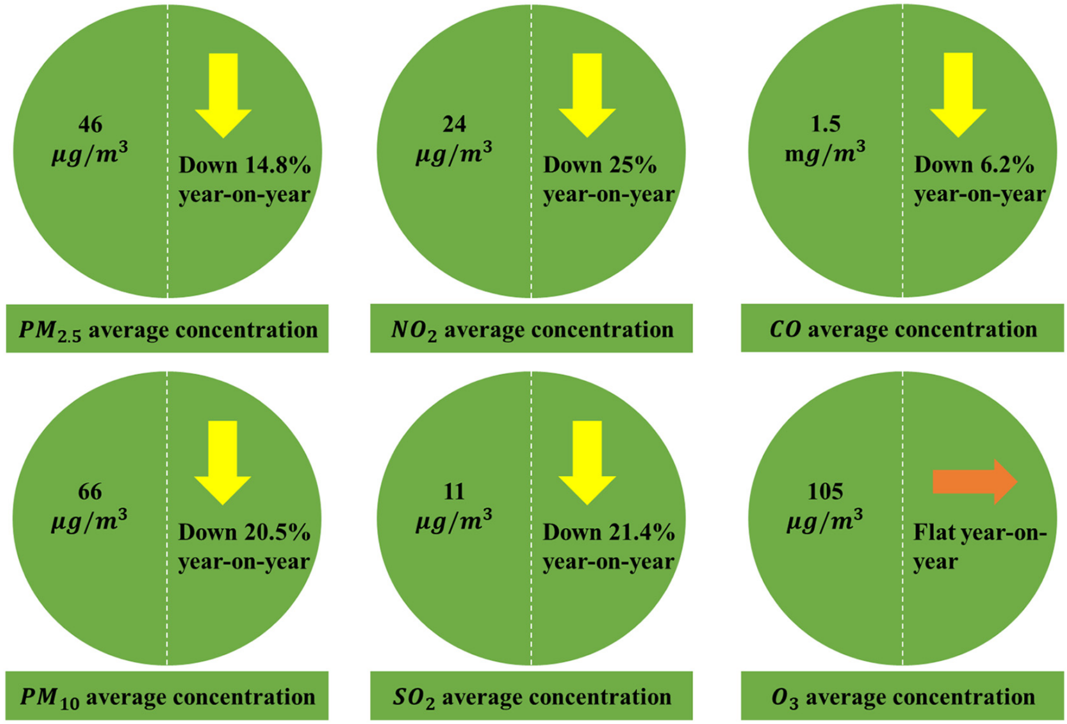

Fig. 11. The concentration of major pollutants and the year-on-year change in the first quarter of 2020.
Source: (Ministry of Ecology and Environment of China, 2020).

(1) The outbreak of COVID-19 improved China's air quality in the short term and significantly contributed to global carbon emissions reduction. From the time dimension, China's energy consumption dropped sharply during the outbreak of COVID-19, especially the total coal consumption. And COVID-19 effectively suppressed the GHG emissions such as CO_2. However, the observed data indicate that this beneficial effect only occurs during quarantine. As some regions in China lifted the lockdown and enterprises resumed production, people and goods began to flow on a large scale. Meanwhile, declining energy consumption is showing an upward trend, and traffic congestion is gradually returning to the level before quarantine. It can be deduced from this that when China completely lifts the lockdown and resumes production, its energy use and GHG emissions are likely to exceed the level before the outbreak.
(2) The COVID-19 significantly reduces the concentration of NO_2 in the atmosphere. This reduction initially occurred near Wuhan and eventually spread to the whole country. From a spatial perspective, the reduction of environmental pollutants initially appeared in areas with severe epidemics because they firstly implemented strict restrictions. Subsequently, more and more regions adopted quarantine measures and implemented traffic control. As a result, the air quality throughout the country improved significantly. This phenomenon seems to imply a close correlation between the economy and environmental pollution. The reduction in economic activities and traffic restrictions directly affects the changes in China's energy consumption, and effectively reduce the generation of environmental pollution.
(3) This study enriches the theoretical research on economic and environmental pollution in the context of extreme events. The COVID-19 outbreak in 2020 is an extreme event and a global emergency public health event. The systematic analysis of the relationship between economic growth and environmental pollution during the outbreak can not only provide a reference for other countries to assess the impact of COVID-19 on the environment, but also enrich the theoretical research on the relationship between economy and pollution from an emergency-economy-environment perspective.

CRediT authorship contribution statement

Qiang Wang: Conceptualization, Methodology, Software, Data curation, Writing - original draft, Supervision, Writing - review & editing. **Min Su:** Software, Data curation, Investigation, Writing - original draft, Writing - review & editing, Methodology.

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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