Past and future trends of civil airport emissions in China, from 2010 to 2030

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Abstract

This paper aims to study the trend of aircraft emission in China. The multiyear emission inventories of HC, CO, NO_X, SO_2 and $PM_{2.5}$ in the period 2010–2030 were developed. Results show that the total amount of all targeted pollutants from China's civil airports climbed from approximately 82407 tons in 2010 to 164275 tons in 2019. It is expected that the total amount of pollutants will reach 400845 tons by 2030. Pollutant emissions had the lowest growth rate in 2019 and the highest growth rate in 2013 (4.1% and 13.3%, respectively). From 2013 to 2019, the rate of increase in airport pollutant emissions began to decline. In 2019, the emissions of HC, CO, NO_X, SO_2 and $PM_{2.5}$ are 6251, 53614, 97059, 6248 and 1102 tons, respectively. COVID-19 had a significant impact on airport emissions. By comparing the statistical value and the predicted value of airport emissions in 2020, we found that COVID-19 reduced the emissions of ZHHH and national by 46.33% and 30.45% respectively. In 2019, the East has the highest contribution rate of 27.6%, and Xinjiang has the lowest contribution rate of 3.6%. The emissions of the seven aviation regions were in the order of east > central south > southwest > north > northeast > northwest > Xinjiang.

1. Introduction

As an important supporting industry for the economic and social development of various countries, the civil aviation industry is not only a means of transportation, but also a fast channel for regional economies to integrate into the global economy (Fan et al., 2012). China is the world's second largest air transportation market, after the United States, and the average annual growth rate of the civil aviation industry has maintained double-digits for many years (Liu et al., 2019). This growth rate far exceeds the growth rate of GDP and other modes of transportation, and the growth of the aviation industry is expected to continue in the foreseeable future (Chen et al., 2017). With the rapid development of civil aviation, pollution also increased, as did the impact on the surrounding environment and region (Ashok et al., 2013; Unal et al., 2005; Woody et al., 2011). These emissions have an adverse effect on the environment and endanger human health; $PM_{2.5}$ are harmful to the lungs and heart (Arunachalam et al., 2011), NO_X is harmful to the human respiratory system and immune function (Barrett et al., 2010; Simonetti et al., 2015; Song et al., 2015), HC and NO_X will further undergo photochemical reactions under strong sunlight, forming highly toxic photochemical smog (Stettler et al., 2011; Yim et al., 2013).

Establishing a pollutant emission inventory the basis of establishing effective measures for developing pollution control strategies (Keogh et al., 2009; Liu et al., 2018; Réquia et al., 2015). Song and Shon. (2012) used the emission and diffusion simulation system to estimate the emissions of air pollutants from aircraft in South Korea for two years (2009–2010). China's research on airport pollution emission inventory started late, and there are few studies. Zhou et al. (2019) developed a flight time/flight height relationship, and calculated the actual time for each flight. Fan et al. (2012) calculated the fuel consumption and HC, CO, NO_X, and CO_2 emissions based on the 2010 China flight schedule, aircraft and engine combination information. Qun et al. (2014) established a calculation method for pollutant emission inventory based on the ICAO standard LTO cycle. All of the above studies contribute to our understanding of the aviation emission characteristics in China, however most studies have shortcomings, such as: (1) Without considering boundary layer changes. (2) Some of which focused only on local or developed areas such as Shanghai (Xu et al., 2020), Beijing (Li et al., 2018) and Guangzhou (Huang et al., 2014). (3) The studies only considered a single year. Considering that the aviation industry will continue to develop rapidly, China's airport pollutant emissions and their characteristics should be further analyzed and studied.

Previous studies on individual aircraft emissions were mostly based on the recommended ICAO method. The ICAO standard LTO cycle defines the MLH as 3000 ft (915 m) above the surface, however the actual MLH varies in different regions. In our previous research (Yang et al., 2018; Zhou et al., 2019), We developed a flight-time/flight-height relationship using real-time height information in Aircraft Meteorological Data Relay data, and then calculated the actual time for each flight based on the actual MLH from meteorological observation. Accurate estimation of national airport emissions requires data from all airports, which is often unrealistic to obtain in some cities in developing countries. Therefore, we divide the national airports into four levels, and select representative airports for each level. Estimate the emissions of national airports by calculating the emissions of these representative airports. Seven typical airports were defined according to the concept of level four airports based on passenger turnover volume, and the emission factors of the four levels of airports based on the number of takeoffs and landings (LTO) were calculated to establish the national airport emission inventory from 2010 to 2030, and the emission inventory was used to analyze the characteristics of annual air pollution regular emissions. The spatial distribution of emissions from 238 civil airports in 2019 was established using ArcGIS. The COVID-19 pandemic and ensuing lockdown of many cities have caused rapid changes in people's travel (Chen et al., 2021; Xiang et al., 2020). The impact of these changes on airport emissions has been quantitatively analyzed.

2. Materials And Methods

2.1 Selection and classification of typical airports

Scientific and reasonable classification of airports has very important practical significance for the country to formulate airport layout and development plans, airline route planning and design, airport function positioning, and development strategies (Suau-Sanchez et al., 2015). For a long time, based on different purposes and uses, the classification methods of China's civil transport airports have diversified and quantitative description methods. For example, principle of maximum information quotient, principal component analysis, clustering analysis, and neural network technology have been used. Based on the center and fractal theory, Cao et al. (2016) studied the spatial structure characteristics of China's airport system, selected the annual passenger turnover of the airport as the quantitative parameter, and concluded the airport classification standards of China's civil airports determined by the annual passenger throughput to be: 12, 2, 0.4 and below 0.4 million, respectively corresponding to first, second, third, and fourth level airports.

Taking passenger turnover as a benchmark and considering the regional economic level of the city where the airport is located, airport operating conditions, airport scale construction, and future airport development positioning, and comprehensively analyzing the airport's aviation activity level and economic benefits, seven typical airports were selected. The main typical airports selected were: Capital International Airport (ZBAA), a large international airport representing North China; Pudong Airport (ZSP), a large airport representing East China; Tianhe Airport (ZHHH); a large airport representing Central China; Zhongchuan Airport (ZLLL), a airport representing Northwest China; Mianyang Airport (ZUMY), a airport representing Southwest China; Foshan Airport (ZGFS), a airport representing South China; and Jinzhou Airport (ZYJZ), a airport representing Northeast China. These seven typical airports were the main object of this study. ZBAA, ZSP, and ZHHH are located in the political and economic centers which are responsible for the transportation of international metropolises, Beijing, Shanghai, and Wuhan, with passenger turnover accounting for more than 10% of the country. The main-line airports represented by ZLLL and ZUMY are generally located in provincial capitals (autonomous regional capitals, municipalities directly under the central government), and important open cities, tourist cities, or other economically developed and densely populated cities and have relatively large passenger volumes. Regional airports have the characteristics of small flight types, small aircraft and cargo turnover volume, mainly with small Airbus and Boeing aircrafts, and low passenger utilization, such as ZGFS and ZYJZ. ZBAA, ZSP, and ZHHH belong to the first level, ZLLL belongs to the second level, ZUMY belongs to the third level, and ZGFS and ZYJZ belong to the fourth level. The flight schedules were used to calculate the airports' LTO cycle emissions, which were obtained from the Civil Aviation Administration of China (CAAC) and the main airports' official website (http://www.caac.gov.cn.). Fig.S1 shows the proportion of the seven typical airport models in 2019.

2.2 Emission estimation

2.2.1 Aircraft emissions

The complete working process of the aircraft includes approach, taxi, take-off, climb, and cruise. The emissions during the approach, taxi, take-off, and climb have a direct impact on the air quality around the airport, whereas the cruise emissions mainly cause the loss of the ozone layer, which has little impact on the air quality near the ground (H. et al., 2018). This study mainly considers aircraft emissions, excluding emissions from cruise phase and other emission sources. According to the ICAO standard, a complete LTO cycle (take-off and landing) can be divided into four activities: take-off, climb, taxi, and approach (Onder, 2014). The standard LTO cycle defines the altitude of the atmospheric mixing height as 3000 ft (915m) from the surface. Taking into account the variability of the maximum boundary layer height in different regions and at different times, this article uses the improved method we have previously researched to calculate the emissions of a single aircraft (Yang et al., 2018; Zhou et al., 2019). The working hours of the approach and climb phases were revised to improve the accuracy of the emission inventory. Air pollutant emissions from aircraft under different modes were calculated according to Eq. (1) to (3) (Winther et al., 2015):

$$E_{i,m} = \sum\nolimits_{j} n_j F_{j,m} EI_{i,j,m} t_{j,m}$$

1

where i is the pollutant type (including HC, CO,NO_X,SO_2, $PM_{2.5}$); j is the aircraft type (such as A320, B737); m is the aircraft working stage (approach, taxi, take-off, and climb); E i,m is the emission of pollutant i in the m working stage, nj is the number of engines of the j type aircraft; Fj,m is the fuel consumption rate of the j type aircraft in the m stage, kg/s; EI i,j,m is j the emission factor of pollutant i in the m-stage of the type-j aircraft, g/kg; t j, m is the working time of the j-type aircraft in the m stage, s.

In the LTO cycle, the standard working times of approach, taxi, take-off, and climb are 4, 26, 0.7, and 2.2 min, respectively. In this study, the standard time of take-off and taxi from the ICAO were used, and the time of climb and approach were improved. The calculation equation is as follows:

Climb time:

$$t_{j,m} = t_m \frac{H_j - 304}{915 - 304}$$

2

Approach time:

$$t_{j,m} = t_m \frac{H_j}{915}$$

3

where tj,m is the working time of m stage of j type aircraft; tm is the standard time of m stage specified by ICAO, s; and Hj is the actual effective emission height of type j aircraft, m; 304 is the starting height of aircraft climb specified by ICAO, m; 915 is ICAO's aircraft approach altitude, m.

The ICAO emission factor database includes only NO_X, HC, and CO. This study assumed that the aviation kerosene consumed by the aircraft fully reacts with the air during the combustion process, and the sulfur in the fuel is completely converted into SO_2. According to the MEET plan (Kalivoda, 1997), this study selected an SO_2 emission factor of 1 g/kg. A method of calculating the $PM_{2.5}$ emission factor using the smoke coefficient was established by the Federal Aviation Administration of the United States. As shown in Eq. 4 (Unal et al., 2005).

$$EI_{j,m} = \frac{0.6 \times \left(SN_{j,m}\right)^{1.8}}{1000}$$

4

Where EI j,m is the emission factor for $PM_{2.5}$ in mode m for each engine used on aircraft type j, g / kg; SN j,m is the smoke number for mode m for the aircraft type j.

2.2.2 Different levels of airport emission factors

This study establishes a detailed inventory of seven typical airports that are used to represent level four airports. Eq. (5) is used to calculate the emission factor based on LTO for level four airports. Airports of the same level use the same emission factors, so that a relatively accurate inventory can be obtained without obtaining activity level data.

$$EF_{i,f} = \frac{E_{i,f}}{LTO_f}$$

5

where EFi,f is the emission factor of four levels of airports (ton/y); Ei,f is the total emission of pollutants from airport i in seven typical airports; and LTOf is the number of take-off and landing times of level f airport in seven typical airports.

2.2.3 Establishment of the national airport inventory

For airports of the same level, passenger turnover, cargo turnover, the proportion of aircraft types, and the social tasks undertaken are similar. Therefore, the emission inventories of the same class of airports were calculated using the same emission factors. The Chinese airport emission inventory was calculated using Eq. 6.

$$E_T = \sum\nolimits_f EF_{i.f} \times LTO_f$$

6

Where E_T is E is the total emissions, and LTOf is the number of take-off and landing times of the level f airport.

2.3 Future projections of LTO

The elasticity coefficient method is an indirect forecasting method that predicts the development and change of another factor through the elasticity coefficient on the basis of predicting the development and change of one factor, and is widely used in predicting the emission of mobile sources (He et al., 2005; Liu et al., 2017; Sun et al., 2019). The estimation of LTO is based on the economic elasticity method that associates LTO with GDP per capita, as shown in the following Eq. 7.

$$\mathrm{M} = M_0(1 + e \times a)^{t-t_0}$$

7

Where M is the forecast year LTO; M_0 is the base year LTO; e is the elasticity coefficient; α is the annual GDP growth rate, %; t is the forecast year; t_0 is the base year.

2.4 Method verification

There are few studies on aircraft emission factors, mainly focusing on database verification and application based on the standard takeoff and landing cycle model specified by the ICAO. Chinese airports are classified in a unified manner, and according to the seven typical airports, the weighted average of the airport's emissions is calculated using Eq. 5, as shown in Table S1. The emission factors of the four levels of HC, CO, SO_2, and $PM_{2.5}$ were similar, and the emission factors of the first level of NO_X were significantly larger than those of the other three levels. For HC, the fourth-level airport has the smallest emission factor. This is because the fourth-level airport is mainly composed of A320 and B737, and the HC emission factors of these two types of aircraft are relatively small. For CO, NO_X, and SO_2, the emission factors of first-level airports were significantly higher than those of other types of airports. This is because the proportions of B738, A321, and A333 in the first-level airports is relatively high. The CO, NO_X, and SO_2 emission factors were relatively large. The main function of third-level airports is to transport people and goods to small cities. The proportion of ERJ series (between regional jets and small single-aisle trunk jets) aircraft at this level of airports is relatively high, and the $PM_{2.5}$ emission factor of ERJ series aircraft is relatively large. The differences in the emission factors of the four levels of airports also reflect the differences in Chinese airports. It is not accurate to use a single emission factor to calculate the emission inventory.

So far, research works on the emissions of civil airports using AMDAR data are limited. Therefore, we only compared the pollutant emissions of a few typical airports with previous studies (Wang et al., 2020; Xu et al., 2016; Yang et al., 2018). The emission inventories of the corresponding airports were calculated using the emission factors of the four airport levels, and the correlation was further analyzed. Fig.S2 illustrates the scatter and fitted straight line between the results of this research and other research results. It is shown that there is a good linear relationship between them, and the square of the correlation coefficient is greater than 0.75. The minimum square of the $PM_{2.5}$ correlation was 0.76, and the maximum square of the CO correlation was 0.99. The correlations calculated in this study were similar to previous research results, indicating that the calculation method proposed in this study is suitable for the calculation of Chinese airports.

3. Results And Discussion

3.1 Trend of emissions

3.1.1 Inter-annual trend of the national emissions

The elasticity coefficient method is used to predict LTOs from 2021 to 2030, which has been proved to be accurate by many studies (He et al., 2005; Liu et al., 2017; Sun et al., 2019). In order to verify the estimated value, the statistical values of typical airports and national LTOs in 2018 and 2019 are selected and compared with the estimated value. The results show that the difference of national LTOs in 2018 and 2019 is 1.3% and 4.2% respectively. The difference of other typical airports is 0.74–5.1%, which is in the acceptable range, and the predicted value of elastic coefficient method has a certain reliability.

Based on the method described in Sect. 2, the airport emissions of HC, CO, NO_X, SO_2 and $PM_{2.5}$ in China from 2010 to 2030 were estimated (as shown in Fig. 1). In the past decade, the total amount of all targeted pollutants from China's civil airports climbed from approximately 82407 tons in 2010 to 164275 tons in 2019 (Emissions in 2020 will be discussed in detail in Sect. 3.1.3). Pollutant emissions had the lowest growth rate in 2019 and the highest growth rate in 2013 (4.1% and 13.3%, respectively). From 2013 to 2019, the rate of increase in airport pollutant emissions began to decline. In the next decade, airport emissions will continue to increase, reaching 400845 tons in 2030. In 2019, the emissions of HC, CO, NO_X, SO_2 and $PM_{2.5}$ are 6251, 53614, 97059, 6248 and 1102, with contribution rates of 3.81, 32.64, 59.08, 3.80 and 0.67% respectively. There is no doubt that NO_X is the pollutant with the highest proportion, which is consistent with previous conclusions (Xu et al., 2016; Yang et al., 2018). NO_X is harmful to human lungs and is one of the main causes of acid rain. Therefore, we strongly recommend that effective measures be taken to curb such large-scale NO_X emissions from Chinese airports, especially to improve air quality and related public health.

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Figure 1 Annual LTO cycle emission inventory of civil aviation airport

In civil aviation transportation statistics, total transportation turnover is used as a comprehensive index to reflect the actual annual passenger and cargo turnover. According to the characteristics of China's civil aviation transportation industry, we set the emission intensity of pollutants emitted by transporting one ton of cargo for one km. Total transportation turnover was obtained from CAAC (http://www.caac.gov.cn/index.html). As shown in Fig. 1, the emission changes of the five pollutants are similar, and the overall trend is decreasing, but there are one peak and two valleys. The emission intensity of NO_X decreased from 0.91 $g \cdot ton^{-1} \cdot km^{-1}$ in 2010 to 0.75$g \cdot ton^{-1} \cdot km^{-1}$ in 2019, with an average annual decrease of 0.016$g \cdot ton^{-1} \cdot km^{-1}$. There were two valleys, in 2011 and 2013, with emission intensities of 0.89 $g \cdot ton^{-1} \cdot km^{-1}$and 0.75 $g \cdot ton^{-1} \cdot km^{-1}$, respectively. With the rapid development of the aviation industry, aircraft have gradually become a conventional means of transportation, and the passenger load rate and efficiency of aircraft use have increased. All these factors reduce the emission intensity of airports. The Ministry of Ecology and Environment estimated the emissions of HC, CO, NO_X, and PM from vehicles in China from 2010 to 2019 (http://www.mee.gov.cn/). Combined with the calculation results of this study, Table S2 shows that the proportions of HC, CO, NO_X, and PM emissions in China's civil aviation airports are relatively low. The average proportions of HC, CO, NO_X, and PM in the latter were 0.13, 0.17, 1.2 and 0.28%, respectively, but their proportions are rising, from 0.06, 0.07, 0.8, and 0.09% in 2010 to 0.33, 0.70, 1.53% and 1.49% in 2019. Although the number of vehicles has been growing, the government attaches great importance to the prevention and control of motor vehicle pollution, and has successively issued policies to control oil products and improve emission standards. Similar to the treatment of vehicle pollution, the government should also strengthen the control of airport pollutants.

3.1.2 Inter-annual trend of the region emissions

The CAAC divides the national civil aviation industry into seven regional aviation administrations, namely the North China Regional Administration, Northeast China Regional Administration, Central South China Regional Administration, East China Regional Administration, the Southwest China Regional Administration, Northwest China Regional Administration, and Xinjiang Regional Administration. Figure 1 shows the establishment of the annual pollutant emission inventory of seven regional aviation administrations from 2010 to 2030. In 2019, the East has the highest contribution rate of 27.6%, and Xinjiang has the lowest contribution rate of 3.6%. The emissions of the seven aviation regions were in the order of east > central south > southwest > north > northeast > northwest > Xinjiang. From the annual change in the contribution rate of each aviation region, the northwest, northeast and Xinjiang increased slightly, from 4.7, 5.5, 2.2% in 2010 to 7.3%, 6.5% and 3.6% in 2019 respectively. The main reason for the uneven distribution of pollutants is the unbalanced development of economic level. We further analyze the relationship between emissions and economic level. Figure 2 describes the linear relationship between the total emissions of the five pollutants and GDP in seven regional administrations from 2010 to 2019. In general, there is a good linear relationship between emissions and GDP, and the correlation R^2 is greater than 0.95, except for Northeast. GDP growth in Northeast region has been relatively slow in recent years, but airport emissions have been growing, and the correlation R^2 of 0.37 is slightly lower than other regions. The 2019 GDP contribution rates of the seven regional administrations were analyzed. The two regions with the highest and lowest GDP contribution rates are East and Xinjiang, which is consistent with the emission contribution rate.

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3.1.3 The impact of COVID-19 pandemic on emissions

The COVID-19 pandemic since the end of 2019 has impacted countries around the world. People in closed physical spaces are more likely to be infected with COVID-19. Airports, as public places with strong public service attributes and densely populated public places, belong to areas with a higher risk of viral infection. Effective measures must be taken to strengthen safety management, public health, and epidemic prevention, and greatly reduce crowd mobility. The COVID-19 pandemic has hitherto had a great impact on the aviation industry. In the first quarter of 2020, the total transport turnover of the aviation industry decreased by 46.6% compared with the same period in the previous year, and passenger volume decreased by 53.9% (http://www.caac.gov.cn/index.html). As shown in Fig. 1, COVID-19 has had a significant impact on airport emissions. In 2017, 2018, 2019, and 2020, the total emissions were 147635, 157830, 164275, and 124012 tons, respectively, with change rates of 9.2, 6.9, 4.1 and − 24.1% from the previous year, respectively. From 2013 to 2019, airport emission intensity has been on a decreasing trend, but will increase by 22.6% in 2020. The annual changes in 2019 and 2020 are shown in Fig. 3(a). There was no COVID-19 outbreak in January, and the difference in emissions was small. After the outbreak of COVID-19 in February, emissions dropped significantly, with a year-on-year change of -69%. Since February, China has introduced a series of policies to deal with COVID-19, which has been brought under control. Since March, civil aviation has resumed operations and emissions have increased. The first large-scale outbreak of the COVID-19 was in Wuhan, which had a huge impact on Wuhan. ZHHH and national emissions were used to study the impact of COVID-19. Figure 3 (b) shows the difference between the statistical value and the predicted value, which is defined as the impact of COVID-19 on emissions. COVID-19 has reduced ZHHH and national emissions by 46.33% and 30.45% respectively.

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3.2 Spatial distribution

Pollutant emissions from 238 civil airports in 2019 were calculated. In this study, the peak value of pollutant emissions among the 238 civil airports appeared in the ZBAA, at which the emissions of HC, CO, NO_X, SO_2, and $PM_{2.5}$ are estimated at about 329.3, 3040.1, 6005.9, 357.8 and 52.9 tons, respectively. In addition, ArcGIS software 10.2 was used to calculate the spatial distribution of pollutants at 238 airports in 2019. The spatial distributions of different pollutants are similar. Figure 4 shows the NO_X distribution of national airports in 2019 and the annual change map of major airports. The distribution of pollutant emissions from airports in China is quite uneven, mainly due to uneven economic development and poor population mobility in inland areas. Airports with high pollutant emissions are mainly located in Beijing, Shanghai, Guangzhou, Yunnan, and Sichuan. ZBAA, ZSP, Guangzhou Baiyun Airport (ZGGG), Kunming Changshui Airport (ZPPP), and Chengdu Shuangliu Airport (ZUUU) are the top five airports in terms of pollutant emissions, with the national contribution rates of pollutants are 7.2, 5.7, 5.2, 3.9 and 3.8% respectively. ZBAA, ZSP, and ZGGG are located in the three most developed cities in China, while ZPPP and ZUUU are located in the most famous tourist cities in China with strong population mobility. In addition, Urumqi Bunker Airport, Harbin Taiping Airport, and Sanya Phoenix Airport are the busiest airports in the west, north, and south of mainland China, respectively. From the perspective of inter-annual changes, the NO_X of major airports in China has shown an increasing trend year by year. The number of LTO in large airports is relatively stable, the inter-annual changes in NO_X are also relatively stable, and the inter-annual changes in NO_X in small airports fluctuate greatly.

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3.3 Comparison of estimated emissions

Table S3 shows a comparison between the air pollutant emissions from the studied airports and results from previous studies. Because most of the previous studies used the method recommended by ICAO and did not consider the impact of actual LMH on emissions, emissions were underestimated. This underestimation is mainly reflected in NO_X emission. NO_X is mainly emitted in the take-off and climb stage of the aircraft. The improved method takes into account the actual aircraft altitude, and the calculation of emission is more accurate.

3.4 Study limitations

The uncertainty of emission inventory is mainly caused by the following factors. Firstly, due to the lack of localized aircraft engine emission factors, the emission factors used in estimating individual aircraft emission inventories come from the ICAO flight database. However, in actual flight, they are affected by weather conditions and aircraft operating modes. The working hours, fuel consumption rate and emission factors of each stage of the aircraft are not the same as the ideal values, so there are uncertainties. Secondly, seven airports with different scales and geographic locations are selected to estimate the national airport emissions. The number and types selected are limited, which may cause uncertainty due to insufficient representation. Thirdly, the elasticity coefficient method is used to estimate aircraft emissions in the next decade. The GDP growth rate in the next decade is the average value of GDP in the past decade, which is uncertain.

4. Conclusions

Accurate estimation of national airport emissions requires data from all airports, which is often unrealistic to obtain in some cities in developing countries. Therefore, we divide the national airports into four levels, and select representative airports for each level. Estimate the emissions of national airports by calculating the emissions of these representative airports. Seven typical airports were defined according to the concept of level four airports based on passenger turnover volume, and the emission factors of the four levels of airports based on the number of takeoffs and landings (LTO) were calculated to establish the national airport emission inventory from 2010 to 2030.

Concerning temporal evolution, the total amount of all targeted pollutants from China's civil airports climbed from approximately 82407 tons in 2010 to 164275 tons in 2019. It is expected that the total amount of pollutants will reach 400845 tons by 2030. Pollutant emissions had the lowest growth rate in 2019 and the highest growth rate in 2013 (4.1% and 13.3%, respectively). From 2013 to 2019, the rate of increase in airport pollutant emissions began to decline. In 2019, the emissions of HC, CO, NO_X, SO_2 and

$PM_{2.5}$ are 6251, 53614, 97059, 6248 and 1102 tons, with contribution rates of 3.81, 32.64, 59.08, 3.80 and 0.67% respectively.

COVID-19 had a significant impact on airport emissions. In 2017, 2018, 2019, and 2020, the total emissions were 147635, 157830, 164275, and 124012 tons, respectively, with change rates of 9.2, 6.9, 4.1 and − 24.1% from the previous year, respectively. By comparing the statistical value and the predicted value of airport emissions in 2020, we found that COVID-19 reduced the emissions of ZHHH and national by 46.33% and 30.45% respectively.

In 2019, the East has the highest contribution rate of 27.6%, and Xinjiang has the lowest contribution rate of 3.6%. The emissions of the seven aviation regions were in the order of east > central south > southwest > north > northeast > northwest > Xinjiang.

Declarations

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Author contribution

Kai Wang: Data Collection and Investigation, Methodology, Writing, and Editing.

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Ethics approval

As authors, we approve that our manuscript does not include the following statements;

• Disclosure of potential conflicts of interest

• Research involving human participants and/or animals

• Informed consent

Consent to participate

As authors, we consent to participate.

Consent to publish

As authors, we consent to publish.

Competing interests

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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Figures

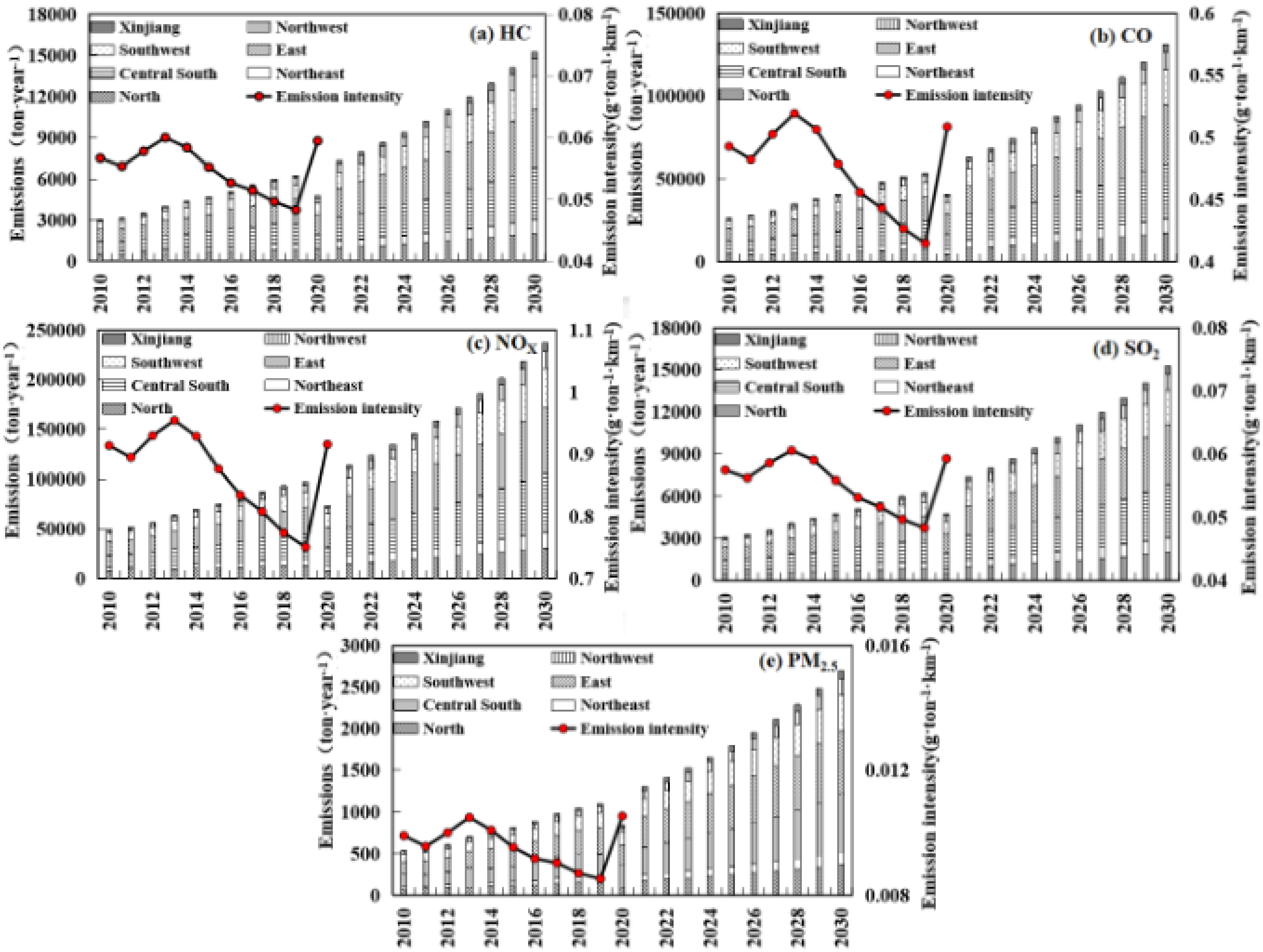

Figure 1

Annual LTO cycle emission inventory of civil aviation airport

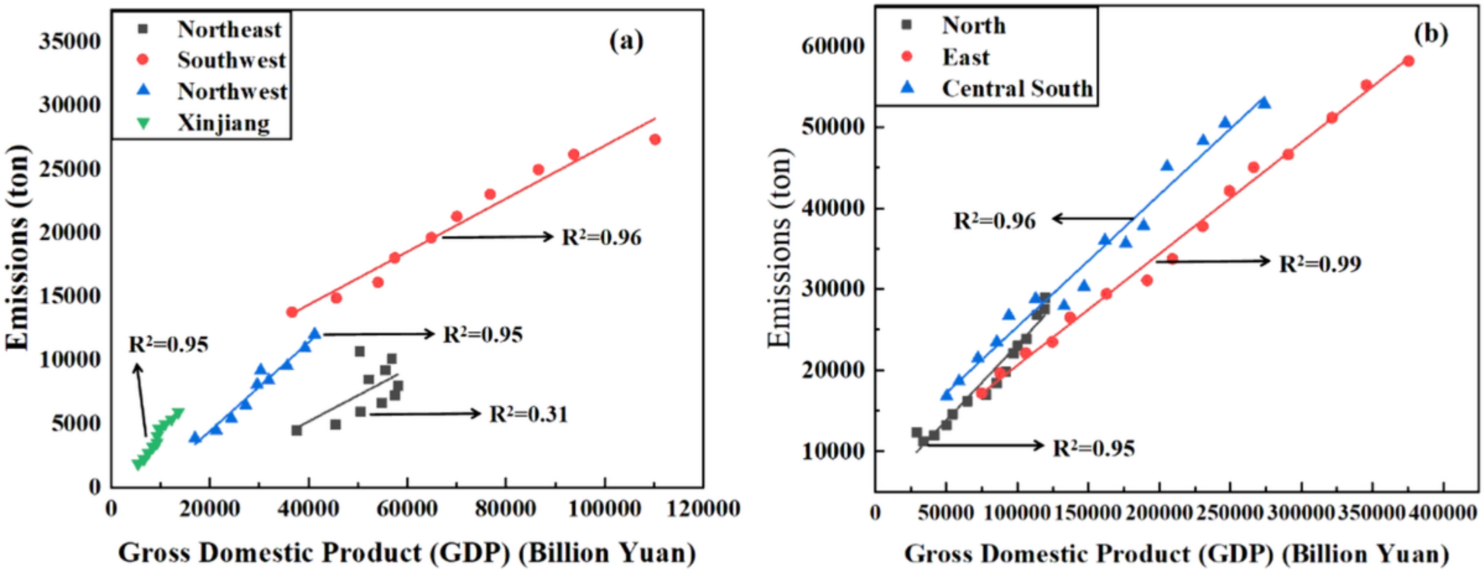

Figure 2

Relationship between emissions and GDP in the seven regional aviation administrations

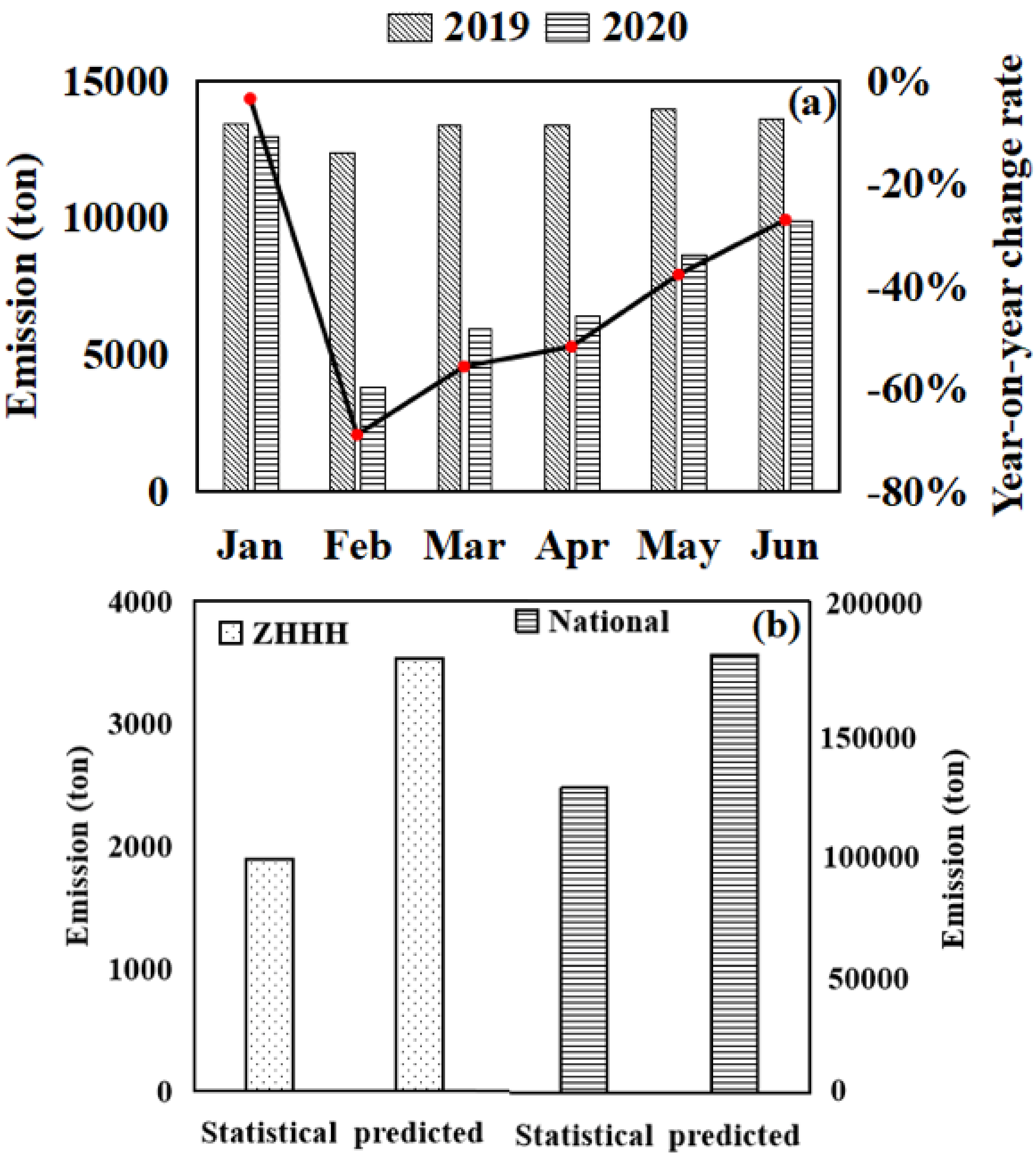

Figure 3

Comparison of emissions during COVID-19 pandemic

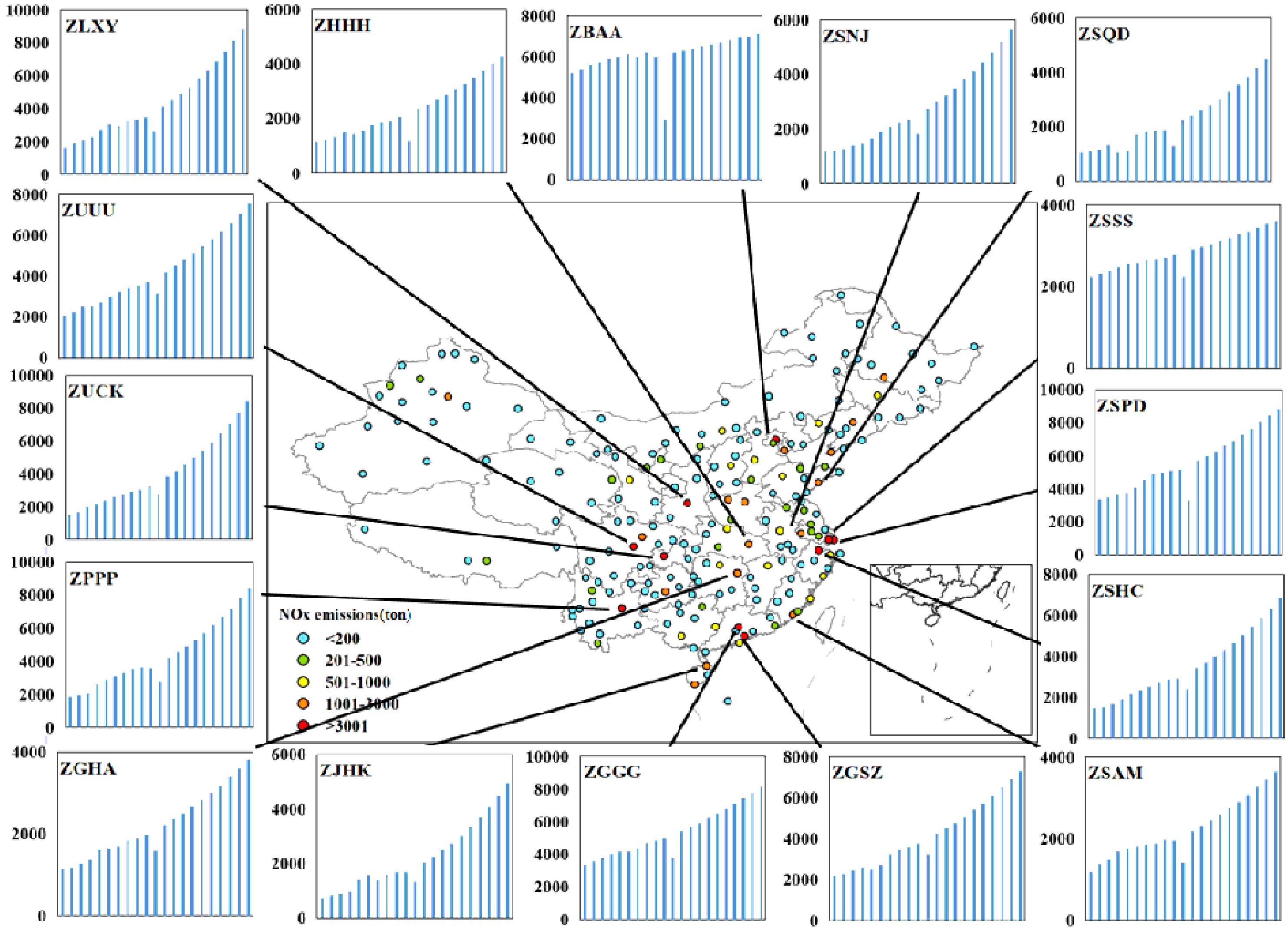

Figure 4

Distribution of NOX emissions from airports in China and inter-annual changes in major airports. The horizontal axis of bar graph presents the year 2010-2030. The numbers of top left corner present ICAO airport code.

Supplementary Files

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