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Research article

Using a bottom-up method to assess cruise ship activity impacts on emissions during 2019–2020 in China

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ABSTRACT

COVID-19 has had a serious impact on the development of the global shipping industry, especially since the impact on the cruise tourism industry was unprecedented. This study took cruise ships sailing in China ECA, China Exclusive Economic Zone (EEZ), Yangtze River main line, and Xijiang River main line Chinese waters as an example to analyze the key changes in cruise ship emissions during the pandemic. Automatic identification system (AIS) data, vessel static data, and emission control regional data are used to conduct a comprehensive analysis of cruise ship emissions from multiple perspectives such as a port-to-regional comparison. As such, a vessel emission model (i.e., a bottom-up method) is constructed in this research for predicting China ECA and EEZ cruise ship emissions. Compared with 2019, the cruise activities sailing in China's Emission Control Area (ECA) are mainly at berth, and the emissions of cruise ships have dropped significantly, with SOx emissions reduced by 59.11%. In addition, this study also calculates the carbon emissions of China's regional cruises, supplementing China's cruise carbon pool. The research results suggest that cruise operators may improve fuel efficiency, decrease vessel speed, improve routing and scheduling, and enhance fleet management in order to further mitigate the negative effects of the cruise tourism industry on the marine environment.

1. Introduction

Cruise shipping is recognized as a major passenger transport alternative worldwide. Cruise lines are passenger vessels provided for leisure, entertainment, and sightseeing. Traditionally, the cruise market is mainly focused on the Caribbean and North American regions. However, an emerging market has arisen in the Asia-Pacific region since 2000 due to high-quality onboard facilities, attractive shore excursions, interesting cruising routes, and unexpected cultural experiences [1,2]. In response, international cruise lines have struggled against strategic development, resulting in a significant enlargement in the volume of passengers and cruise lines [3].

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Experiencing over 10 years of rapid development in cruise commerce, China has become one of the most significant regions in the global cruise market. The number of home-port tourists taking leave in China was recorded as more than 2.40 million in 2017, contributing to almost 60% of the Asian market [4]. According to the statistical data from the Cruise and Yacht Industry Association (CCYIA), a branch belonging to the China Transportation Association, from 2012, the number of cruise calls increased remarkably in mainland China, see Fig. 1. In 2016, China outstripped Germany for the first time to become the second-largest cruise origin market, receiving 1010 cruise visits, and over 1.45 million passengers [5].

The worldwide outbreak of the COVID-19 pandemic severely threatens human health, fundamentally changes people's lifestyles and industrial activities, and significantly influences worldwide economic growth [6,7]. The first reason is the quick transmission of the global epidemic has directly induced a remarkable increase in unpredictable economic development, which has caused disturbance in capital and financial markets. The second reason is countries have rigorously limited the movement of transportation and people to control the transmission of the virus. To a certain extent, the virus mainly transmits from person to person once in close contact through small droplets created by sneezing, talking, and coughing. As such, the economic activities have been dramatically decreased [8]. The outbreak of the COVID-19 pandemic was stated as a Public Health Emergency of International Concern in January 2020, as well as a pandemic in March 2020 by the World Health Organization [9]. In 2020, because of the outbreak of COVID-19, most cruise ships operated by international cruise lines moved out of mainland China, and the Chinese government adopted tightened lockdown measures and stringent regulations for access to public tourism facilities and services. The rapid development of regional cruise shipping in China is bound to have certain impacts on the environment [10]. Chen et al. [11] pointed out that cruise transportation was significantly affected during the pandemic. Therefore, it is necessary to explore the vessel characteristics of regional cruises in China and their environmental impacts before and after the pandemic to guide the development of regional cruise shipping in China.

The expansion of the cruise industry also causes negative impacts of cruise tourism in city destinations. It becomes crucial because of its inclination to be environmentally unsustainable, influencing particularity transition and developing countries [13]. In general, cruise vessels consume heavy fuel oil, notably residual oil which has a complicated structure and generates hazardous elements like sulphides. Cruise vessel emissions involve various hazards and risks to ocean acidity and human health (e.g. respiratory diseases) [14]. Additionally, the rise and control of cruise shipping emissions is a key task in port governance. In response, Domestic Emission Control Areas (DECAs) strive towards mitigating air pollution in regions along rivers, and in coastal areas, notably Chinese port cities. These include the Bohai Rim (i.e. Hebei, Tianjin, and Beijing), the Yangtze River Delta area, and the Pearl River Delta area [15,16]. Up to now, the Chinese government has established comprehensive cruise port systems in various cities, including Guangzhou, Shenzhen, Qingdao, Dalian, Shanghai, Xiamen, Zhoushan, Tianjin, Sanya, etc. As expected, the introduction of an environmentally friendly operation concept may promise a revival for the cruise tourism industry in the post-COVID-19 pandemic era [17].

Growth in cruise shipping leads to increasing concern about environmental impacts [15]. Cruise vessels use heavy fuel with a complex composition that produces more dangerous substances, such as sulphur. Thus, the key environmental concern is cruise ship emissions [18,19]. To address the critical research concern and attract interest, there have been numerous previous research studies related to cruise ship emissions. Howitt et al. [20] computed the CO_2 emissions generated by cruise shipping in New Zealand. Also, the features of vessel emissions and the impacts of vessel sizes were explored by Walsh and Bows [21]. Maragkogianni and Papaefthimiou [22] assessed the air emissions by cruise vessels for the popular Greece cruise ports. Moreover, Poplawski et al. [23] explored the effects of cruise vessel emissions in Victoria. Further, Dragović et al. [24] performed an examination and calculation of vessel exhaust

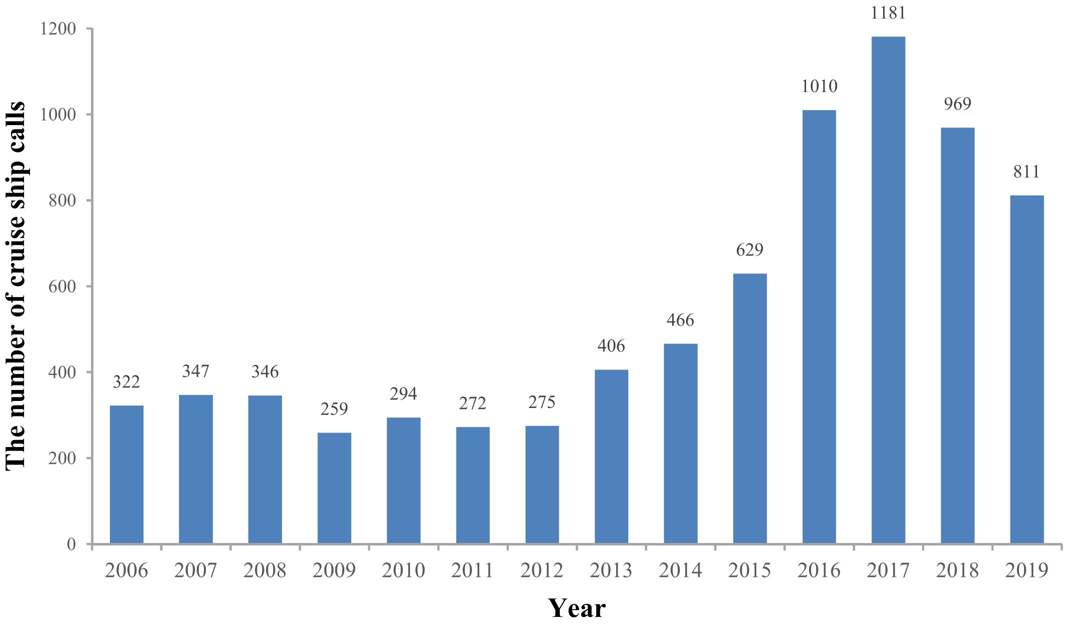


Fig. 1. Number of cruise vessel calls in mainland China [12].

emissions and their externalities in the recognized cruise destinations of Kotor and Dubrovnik. In general, most of the researchers are inclined toward cruise vessel emissions for cruise ports, and this pattern confirms that cruise ports are encountering substantial air pollution by cruise vessels [18].

Cruise vessel emissions create environmental hazards [25]. Maragkogianni and Papaefthimiou [22] assessed cruise vessel emissions in the five biggest ports in Greece by considering activity, seasonality, and gas types. They revealed that seasonality makes significant increases in emissions, especially in summer. Dragović et al. [24] performed an analysis to estimate vessel emissions and their externalities in Kotor and Dubrovnik ports. They found that cruise ships generate continuously increasing pollution in the ports. Berthed cruise ships using marine fuel affect the levels of emissions. Zhen et al. [15] used a mixed integer programming model to optimize cruise vessel speed, sailing pattern, and port-of-call sequences to reduce fuel costs for ships. They found that by using the model, fuel costs could be significantly reduced. Zheng et al. [26] adopted an artificial neural network model to estimate the relationship between energy expenditure and operation parameters for cruise vessels at sea to minimize fuel consumption on a voyage and found that the total fuel consumption was reduced. Fabregat et al. [27] employed machine learning to predict emissions at the Port of Barcelona and the impact of its cruise activities on urban air quality. Furthermore, Tzannatos [28], Maragkogianni and Papaefthimiou [22], and Dragović et al. [24] adopted a bottom-up approach based on estimated ship operating modes at ports to calculate the external cost estimation from ship emissions (i.e., $PM_{2.5}$, NO_x, and SO_2).

Chen et al. [29] conducted research on cruise ship emissions during COVID-19 and investigated the global cruise shipping affected by the pandemic using ship traffic density and emission models. They found that the pandemic affects cruise ship activities and led to the emission rate decreasing during the pandemic. In response, Wang et al. [30] also pointed out that global carbon emissions has sharply decreased by almost 7% compared to 2019. Wang et al. [18] criticized that the cruise industry research studies have been dominated by various tourism researchers in past decades. In past research studies, the authors mainly focused on optimization and itinerary design. Also, past research studies mainly examined port emissions. However, cruise ship emissions are still not explored to

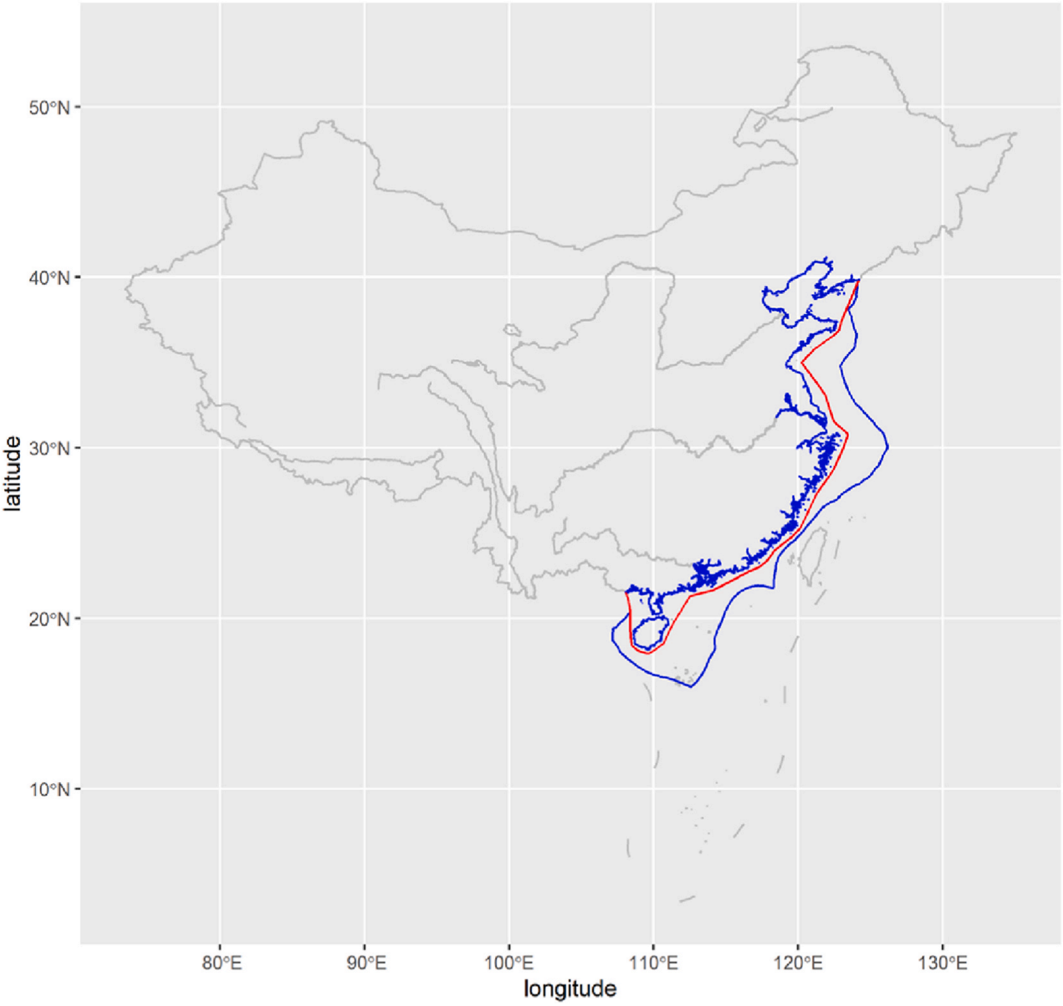


Fig. 2. Study Area. Notes: China ports*, excluding China’s Taiwan.

the required extent [31], notably in China. Furthermore, the domestic research studies relevant to the emission characteristics of cruise vessels with various engine types and different vessel models remain under-researched. Thanks to the Paris Agreement, numerous countries have decided to adopt carbon neutralization strategies as their emission reduction goals in the middle of the 21st century. As such, the objective of carbon neutralization is vital, with more than 160 countries attempting to attain the net-zero emission goal via environmental regulations and green technology [32,33]. In particular, China relies on carbon reduction strategies along with its ‘dual carbon” goals of reaching peak emissions and carbon neutrality by 2030 and 2060, respectively. In the meantime, the worldwide carbon emissions have largely reduced from the effects of the COVID-19 pandemic, which also encouraged discussions about the actual influence of the pandemic on carbon emissions [30].

The structure of this paper is as follows. Section 1 provides the research background, a literature review, and settings. Section 2 presents data sources, study areas, and vessel emission models. The empirical analysis is conducted in Section 3. The major findings from the extensive numerical analysis and concluding remarks are comprehensively discussed in Sections 4 and 5, respectively.

2. Data and methodology

2.1. Data sources

This study includes AIS data and vessel static data. The AIS data was adopted from BLM-Shipping [34]. The AIS data includes the Maritime Mobile Service Identify (MMSI) code, vessel longitude and latitude coordinates, time stamp, ship speed, heading, and other activity information. Ship static data was adopted from Marine Traffic and Right Ship [35,36], which includes the International Maritime Organization (IMO) number, ship length, ship width, ship type, ship gross tonnage, year of construction, design speed, rated engine power, flag, and other information. The ships examined in this study are cruise ships active in China ECA, China Exclusive Economic Zone (EEZ), Yangtze River main line, and Xijiang River main line in 2019 and 2020.

2.2. Study areas

This study mainly explores the differences in the emissions of cruise vessels in China before and after COVID-19. The red line

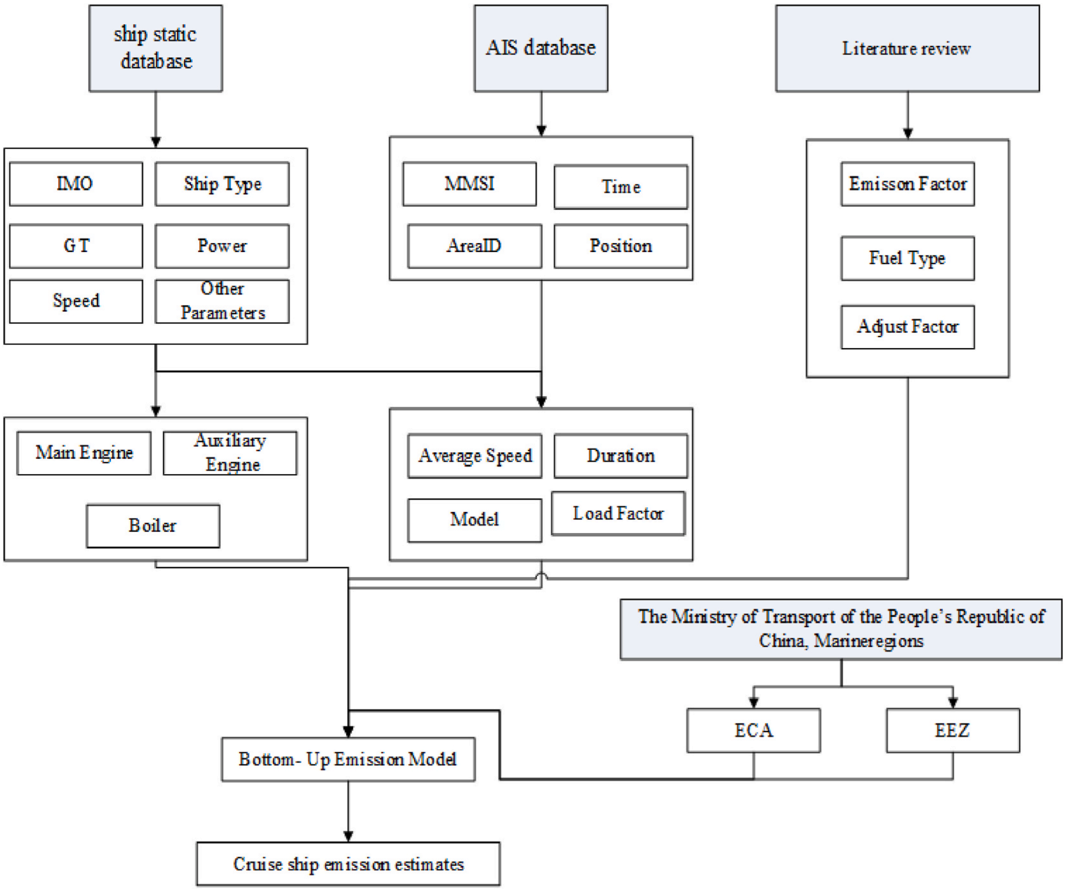


Fig. 3. Adopted roadmap for estimation of cruise ship emissions in the ECA and EEZ.

exhibits China Emission Control Areas (ECA) from the Ministry of Transport of the People's Republic of China [37], while the blue lines show China's EEZ, with EEZ data extracted from Marineregions [38]. The regions covered by the red boundary and blue boundary are shown in Fig. 2. According to the United Nations [39], China's EEZ is defined as "The exclusive economic zone of the People's Republic of China is an area beyond and adjacent to the territorial sea of the People's Republic of China extending to a distance of 200 nautical miles from the baselines from which the breadth of the territorial sea is measured".

2.3. Vessel emission model

Currently, the most common method used to calculate ship pollution emissions is the bottom-up approach based on AIS data. The main calculation models come from the reputable sources [40,41]. The study used the emission estimation model of Comer [41] for quantifying China ECA and EEZ cruise ship emissions. This study constructs an AIS database, ship static database, and emission factor database, which contain ship dynamic information, static information, pollutant emission factors, adjustment factors, fuel types, and so on. Combined with a bottom-up emission model, it calculates the emissions of the main engine, auxiliary engines, and boilers of each ship in the considered study area, and then estimates the pollution emissions of a cruise ship and multiple cruise ships. The holistic roadmap of this study is presented in Fig. 3. Additionally, the bottom-up model is suitable for both river cruises and ocean cruises. The established bottom-up approach is defined by Equations (1) and (2) as follows:

$$E_{ij} = \sum_{t=0}^{t=n} \left(\left(P_{ME_i} * LF_{i,t} * A_{LF,i,t} * EF_{ME_{j,k,m}} + D_{AE_{p,i,t}} * EF_{AE_{j,k,m}} + D_{BO_{p,i,t}} * EF_{BO_{j,m}} \right) \times 1 hour \right) * 10^{-6} \tag{1}$$

$$LF_{i,t} = \left(\frac{V_{i,t}}{V_{max_i}} \right)^3 \tag{2}$$

Where i represents the cruise ship; j represents the pollutants emitted by the cruise vessel, including Sulphur oxides (SOx), Nitrogen oxides (NOx), Carbon dioxide (CO_2), Particulate matter (PM), Carbon Monoxide (CO), Methane (CH_4), Nitrous oxide (N_2O), Non-Methane Volatile Organic Compounds (NMVOC), and Black carbon (BC); t represents the cruise sailing activity time (h); k represents the engine of the cruise vessel, including main engine, auxiliary engine, and boiler; m represents the fuel type of the cruise vessel, and this study assumes that the fuel used by the cruise ship is Heavy fuel oil (HFO), Very low sulphur fuel oil (VLSFO), and Marine gas oil (MGO). See Table A.1 of Appendix A for the sulphur content in different regions; p represents the operation mode of the cruise vessel. According to the speed over the ground (SOG), the ship's navigation mode is divided into four categories, namely Berth, Anchored, Maneuvering, and Cruising, for more information, please refer to Chen et al. [11]; E_{ij} represents the emission of pollutant from a cruise ship (tons); P_{MEi} indicates the power of the cruise main engine; $LF_{i,t}$ indicates the load factor of the cruise main engine; $A_{LF,i,t}$ indicates the emission adjustment factor when the main engine load factor is less than 20%. For detailed information, refer to Chen et al. [14]; $V_{i,t}$ represents the ground speed of the cruise vessel; V_{maxi} represents the design speed of the cruise vessel; $EF_{MEj,k,m}$ represents the main engine emission coefficient (g/kWh) of a cruise vessel under different pollutants, engine types and fuel types. For detailed information, refer to Chen et al. [14]; $D_{AEp,i,t}$ represents the power of the auxiliary engine of the cruise vessel at different times and sailing modes, detailed information refer to Chen et al. [14]; $EF_{AEj,k,m}$ represent auxiliary engine emission coefficients (g/kWh) under different pollutants, engine types, and fuel types. For detailed information, refer to Chen et al. [14]; $D_{BOp,i,t}$ represents the boiler power (kW) of the cruise vessel in different operating modes, for detailed information refers to Chen et al. [14]; $EF_{BOj,m}$ represents the boiler emission coefficient (g/kWh) of the cruise vessel under different pollutants and fuel types, for detailed information, refer to Chen et al. [14].

3. Empirical analysis

3.1. Descriptive statistics

Table 1 displays the AIS dynamic information and vessel static information in 2019 and 2020. For ship static information, relative to 2019, the average gross tonnage of cruise vessels in 2020 reduced by 22.99%, the average rated power decreased by 14.72%, the average design speed increased by 11.79%, and the average max draught increased by 5.44%. For ship dynamic information, in 2020, the AIS records of cruise ships decreased by 73.34%, the total sailing distance decreased by 87.33%, and the total sailing time

Table 1
AIS dynamic information and vessel static information in 2019 and 2020.

		2019	2020	% Change
AIS dynamic information	AIS records	6597287	1758626	−73.34%
	Total sailing distance (nm)	211226.30	26771.50	−87.33%
	Total sailing time (days)	1830.23	1067.33	−41.68%
Vessel static information	Average Gross Tonnage (GT)	92974.10	71600.46	−22.99%
	Average rated power (Kw)	53759.62	45848.66	−14.72%
	Average design speed (Kn)	21.14	23.64	11.79%
	Average max draught (m)	7.45	7.85	5.44%

decreased by 41.68%. After the outbreak, the dynamic information of ships was greatly affected, and the activities of ships were significantly reduced.

Fig. 4 shows the number of cruise vessels sailing in China ECA in 2019 and 2020. Cruise ships in China's ECA region averaged nearly 19 per month in 2019 and nearly 7 per month in 2020. Since February, the amount of cruise vessels has dropped significantly, and in March, it dropped to its lowest point. Compared with 2019, the number of cruise vessels has dropped by 88.89%, which is also the most stringent period of epidemic prevention and control in China. Although the amount of cruise vessels increased in July 2020, only 20.00% less than in 2019, this situation is unsustainable under the normalization of the pandemic. From August to December, the amount of cruise vessels decreased monthly compared to 2019 by more than 68%.

Fig. 5 shows the average cruise speed in the ECA region in China in 2019 and 2020. Cruise ships averaged 11.94 knots in 2019 and 3.51 knots in 2020. Obviously, after the outbreak of the coronavirus epidemic, the cruise ship speed was greatly affected. Since February, the cruise ship's speed has been between 0 and 2 knots in most months, basically in berthing.

Fig. 6 shows the total distance of cruise vessels in the ECA region in 2019 and 2020. The average total distance traveled by cruise ships in 2019 was 17,602.19 nautical miles, and in 2020 it was only 2230.96 nautical miles, a decrease of 87.33%. Obviously, after the outbreak of the new COVID-19 epidemic, the total distance traveled by cruise ships has been greatly affected. Except for January, compared to 2019, the total distance traveled by cruise ships in 2020 has increased by 35.66%. In other months, the total distance traveled by cruise ships has decreased by more than 87%.

3.2. *Vessel emissions*

Taking SO_x and CO_2 as examples in China ECA, the monthly discharges from cruise vessels in 2019 and 2020 are shown in Fig. 7(a) and (b). For SO_x, cruise ships emitted 359.39 and 146.95 tonnes in 2019 and 2020, respectively, a decrease of 59.11% compared to 2019. Fig. 7(a) shows that from February, compared with 2019, the average monthly emissions of cruise vessels in 2020 reduced by 57.14%. For CO_2, cruise ships emitted 357.42 and 141.97 kilotonnes in 2019 and 2020, respectively, a decrease of 60.28% compared to 2019. Fig. 7(b) shows that from February, compared with 2019, the average monthly emissions of cruise vessels in 2020 reduced by 58.28%.

Taking SO_x and CO_2 as examples, the discharges associated with diverse ship operating modes in 2019 and 2020 are shown in Fig. 7 (c) and (d). For SO_x, cruise ships emitted the most pollutants in cruising in 2019, followed by berthing, which accounted for 66.97% and 31.75% of the overall emissions, respectively. After the outbreak, in 2020, cruise ships emitted the most emissions in berthing, followed by cruising, accounting for 80.33% and 18.14% of the total emissions, respectively. After the outbreak, compared with 2019, cruising decreased by 88.92%, while berthing increased by 3.44%. For CO_2, cruise ships emitted the most pollutants in cruising in 2019, followed by berthing, accounting for 67.78% and 31.01% of the total emissions, respectively. After the outbreak, in 2020, cruise ships emitted the most emissions in berthing, followed by cruising, accounting for 79.79% and 18.71% of the total emissions, respectively. After the outbreak, compared with 2019, cruising decreased by 89.04%, while berthing increased by 2.22%.

Taking SO_x as an example, the emissions of main engines, auxiliary engines, and boilers in 2019 and 2020 are shown in Fig. 7(e). In 2019, the main engine and boiler discharges of cruise ships accounted for 44.82% and 5.34% of the total emissions, respectively. After the outbreak, in 2020, cruise vessel discharges from the main engines and boilers accounted for 10.56% and 9.80% of the overall emissions, respectively. Compared with 2019, the cruise main engine emissions decreased by 90.37%, the auxiliary engine emissions decreased by 34.66%, and the boiler emissions decreased by 25.02%.

Table 2 shows the SO_x and CO_2 emissions of cruise ships in 2019 and 2020 for the top ten flags. It can be seen that the epidemic has caused great changes in the emissions of the ship from various countries. The emissions of most countries have been reduced to varying

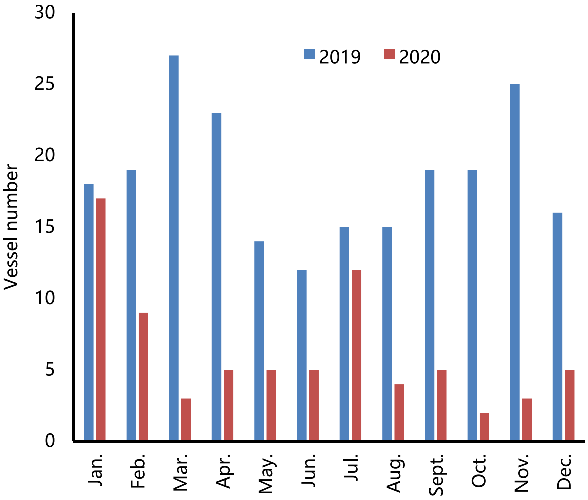


Fig. 4. The Amount of cruise vessels in 2019 and 2020.

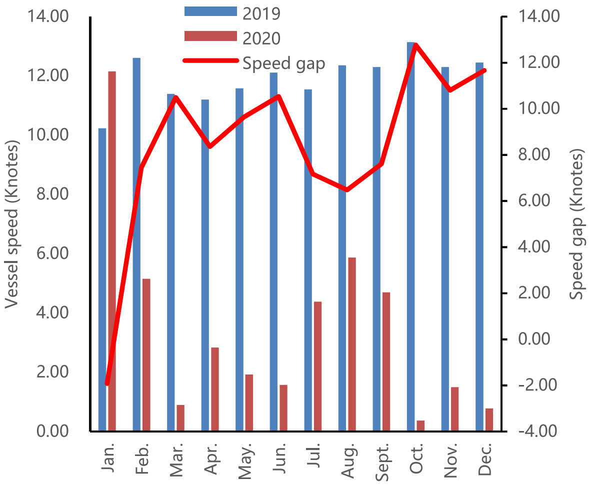


Fig. 5. Average Speed (Kn) of cruise vessels in 2019 and 2020.

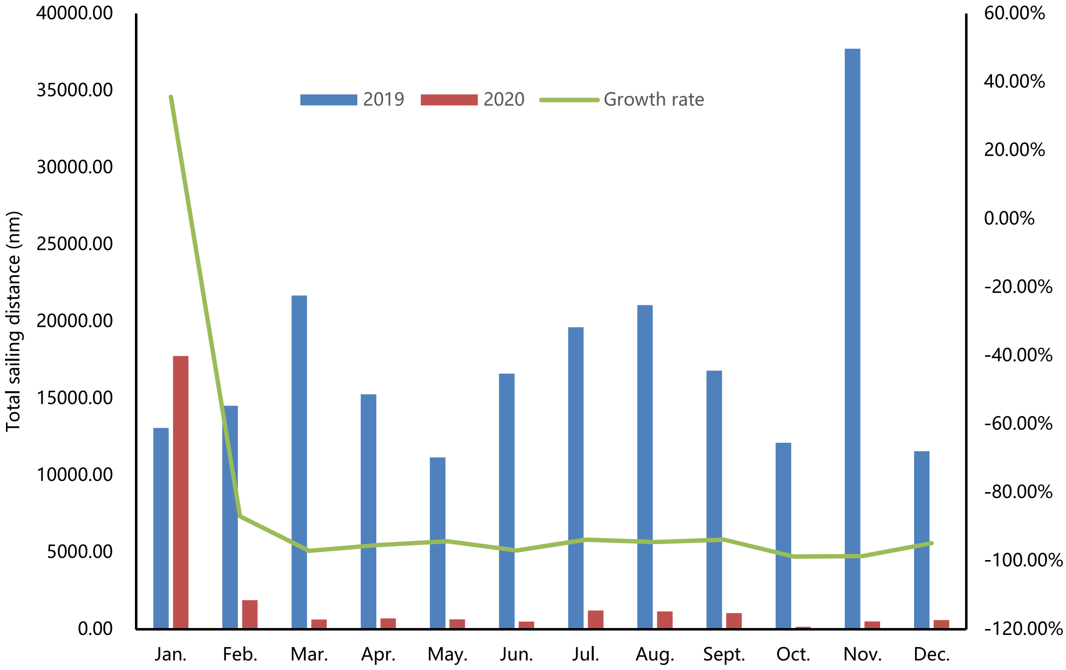


Fig. 6. The total distance (nm) of cruise vessels in 2019 and 2020.

degrees. For example, Japan's CO_2 emission has decreased by 97.91%. However, some emissions increased. For example, Liberia flag ships' SO_x discharges increased by 107.42%, and CO_2 discharges increased by 106.57%. In contrast, Bermuda flag ships' SO_x emissions increased by 636.10%, and CO_2 emissions increased by 617.85%.

3.3. Spatial distribution of cruise ship emissions

Fig. 8(a–d) shows the spatio-temporal distribution of SO_X and CO_2 emissions in 2019 and 2020. Taking SO_X as an example, it can be seen that the discharges of cruise vessels are mainly concentrated in cruise ports and the main routes, with Tianjin Port, Shanghai Port, Guangzhou-Shenzhen Port, Hong Kong, the Bohai Rim route, and the Hainan route as the main emission areas. After the outbreak, the emission intensity of these major cruise ports and routes weakened.

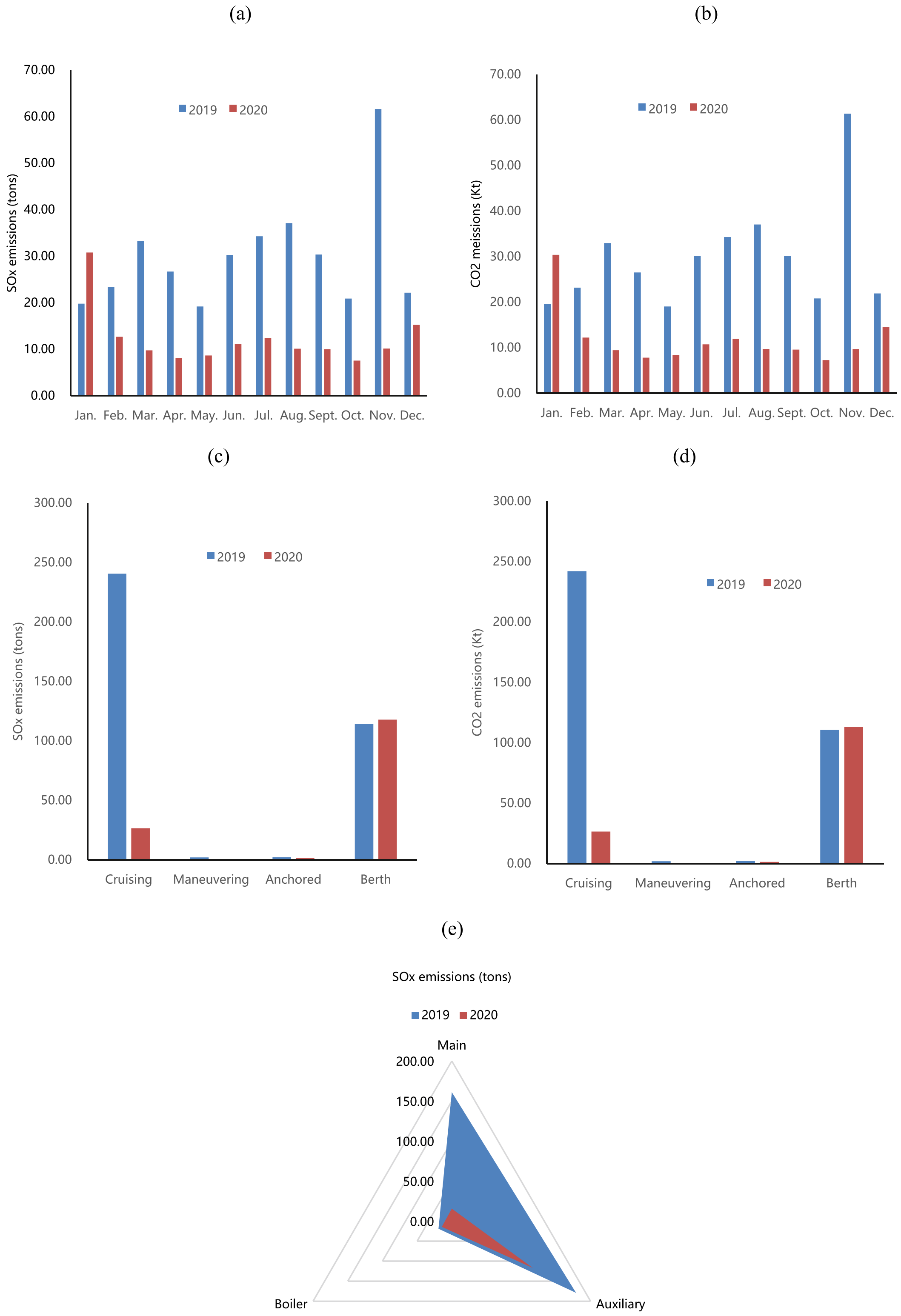
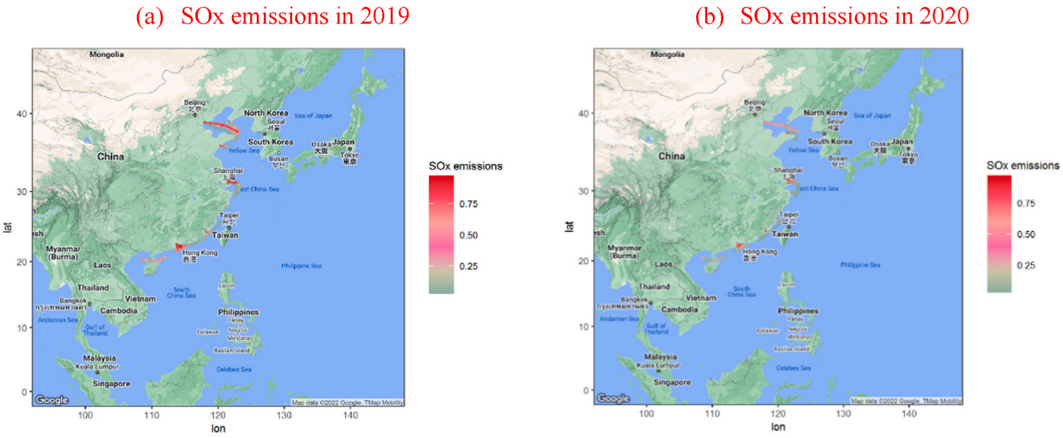


Fig. 7. Vessel emission analysis in China ECA. [Total SO_x emissions (tons) in 2019 and 2020 (a); Total CO_2 emissions (Kt) in 2019 and 2020 (b); SO_x emissions under various vessel operational modes in 2019 and 2020 (c); CO_2 emissions under various vessel operational modes in 2019 and 2020 (d); SO_x emissions from vessel engines in 2019 and 2020 (e)].

Table 2
Top ten flag SO_x emissions and CO_2 emissions in 2019 and 2020.

Flag	SO_x emissions (tonnes)			CO_2 emissions (tonnes)		
	2019	2020	% Change	2019	2020	% Change
Bahamas	128.73	23.61	−81.66%	127903.98	23066.35	−81.97%
Italy	74.57	17.05	−77.13%	74591.70	16772.83	−77.51%
Panama	30.15	3.05	−89.88%	29903.48	2970.65	−90.07%
Liberia	11.39	23.63	107.42%	11443.55	23638.39	106.57%
Malta	9.67	1.72	−82.20%	9473.33	1656.71	−82.51%
Netherlands	7.02	0.97	−86.17%	6878.81	946.38	−86.24%
Bermuda	6.78	49.92	636.10%	6561.42	47101.07	617.85%
United Kingdom	4.66	0.93	−80.08%	4540.29	889.03	−80.42%
Norway	1.00	0.77	−23.27%	1007.35	770.14	−23.55%
Japan	0.26	0.01	−97.89%	264.47	5.52	−97.91%


(a) SOx emissions in 2019 (b) SOx emissions in 2020

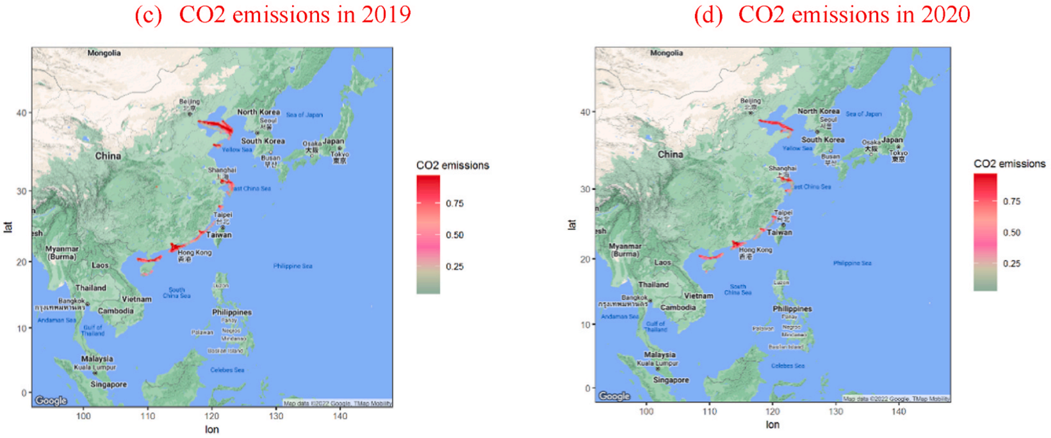

(c) CO2 emissions in 2019 (d) CO2 emissions in 2020

Fig. 8. Spatio-temporal distribution of cruise vessel emissions in 2019 and 2020 [Note: The reddish colour represents a high emission density]. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4. Discussion

This study evaluated different dimensions of the available data and performed a comprehensive emission analysis on cruise ships operated by China ECA in 2019 and 2020. Compared with the time period before 2019, the dynamic information of cruise ships after 2020 has been greatly affected. Many ships' activities have been minimized, and the number and average speed of ships have been reduced. After the pandemic, cruise ships spent most of the time in berthing. From the perspective of emissions, taking SO_x as an example, the emissions of cruise vessels decreased by 59.11% compared with 2019. The cruise status decreased by 88.92% compared with 2019, while the berth status increased by 3.44%. Compared with 2019, main engine emissions, auxiliary engine emissions, and boiler emissions are further decreased by 90.37%, 34.66%, and 25.02%, respectively. As such, the emission intensity of major cruise ports and routes in China has remarkably weakened after the outbreak of COVID-19 pandemic.

In order to further verify the obtained results and gain broader insights, this study takes the Xiamen Port Cruise Terminal as an example. The number of voyages of the Xiamen Port Cruise Terminal are calculated based on AIS data. In 2019, the number of voyages of the Xiamen Port Cruise Terminal was 150. According to the field research, the number of voyages at the Xiamen Port Cruise Terminal is 136. As can be seen from Table 3, compared with the real number of voyages to Xiamen Port, in 2019, the number of voyages to Xiamen Port in this study increased by 10.29%. Considering the uncertainty factors in the processing of AIS data, such a degree of error is within a reasonable and acceptable range (i.e., the findings can be still viewed as valid despite some limitations associated with the AIS data processing).

The study compares the main changes of different indicators of cruise ships in ECA and EEZ via the investigation of the voyage characteristics and emissions changes of cruise vessels in China before and after the pandemic (Table 4). It can be seen that before the outbreak, in 2019, compared with ECA, the static indicators in EEZ (such as Average ship number, Average GT, Average Power, Average Max Draught, and Average Design Speed) changed very little, and the growth rate was 5%. For the dynamic indicators, the cruise ship's ground speed increased by 15.29%, the total sailing time increased by 39.25%, and the number of AIS records increased by 56.52%. Other dynamic indicators (such as Total distance, SOx, NOx, CO_2, PM, CO, CH_4, N_2O, NMVOC, and BC), increased by more than 99%, especially the emission of SO_x increased by 2031.90%. It can be seen that the emissions of cruise ships are mainly concentrated outside China's ECA, and the emissions between ECA and EEZ are higher. After the outbreak, that is, in 2020, compared with ECA, the static indicators of cruise ships in EEZ (such as Average ship number, Average GT, Average Power, Average Max Draught, and Average Design Speed), the growth rate was below 15%, and some even had negative growth, with the Average Design Speed decreasing by 0.90%. For the dynamic indicators, in addition to the total distance and NO_X emissions of ships, the growth rates of other dynamic indicators (Average SOG, AIS record, SO_x, NO_x, CO_2, PM, CO, CH_4, N_2O, NMVOC, and BC) were less than 50%.

5. Conclusions

Changes in cruise ship emissions in China before and after the COVID-19 pandemic were investigated as a part of the present study. The analysis was conducted using AIS data, vessel static data, ECA data, and COVID-19 data. It was found that the pandemic significantly affected the cruise industry in China. Compared with 2019, the number and average speed of cruise vessels reduced to varying degrees, and cruise ships were mostly at their berthing positions. The pandemic has caused a momentous decrease in the emissions of cruise vessels. Taking SO_x as an example, compared with 2019, the discharges in 2020 decreased by 59.11%, and the cruising status decreased by 88.92%. The emissions of the main, auxiliary engines, and boilers were respectively reduced by 90.37%, 34.66%, and 25.02%. The pandemic has caused significant differences in the emission intensity of China's major cruise ports and routes.

Reducing emissions from cruise ships, especially in China, can be undertaken in different ways [42]. Improving fuel efficiency is the most noticeable way to reduce emissions, which can be done by using technical measures to reduce fuel consumption. Another way is decreasing cruise vessel speed which decreases fuel consumption and CO_2 emissions as well. Improving routing and scheduling reflects operational efficiency, which can be further attributed to the minimization of times at cruise ports, especially ports in emission control areas (ECAs). Cruise lines may also redesign itineraries to avoid visiting ECA ports. Enhancing fleet management which is a better ship deployment approach helps minimize downtime for routine maintenance and technical problems.

The China Ministry of Transport announced an advanced action plan for setting up national DECAs indicating China's desire in pursuing outstanding environmental regulations and constructing key mechanisms for possible progress in the IMO ECA initiative in the coming years. Monitoring and assessing the current measures, along with possible studies of possible next steps, are required to stimulate self-confidence and to show the nation's capability and determination to the global community. To effectively achieve the goals of the nationwide DECA in the coming years, the policymakers, international organizations, industrial practitioners, and researchers can collaborate with the Chinese government to analyze the cost-effectiveness of a possible Chinese ECA in the inland waterway systems (i.e. the Pearl River and Yangtze River).

Establishing a green cruise port by using shore power to replace diesel power generation systems for berthed cruise ships has become a common practice worldwide to reduce the emission of harmful substances. As such, the adoption of shore power technology has a significant impact on decreasing the emission of harmful substances (e.g., PM 10, SO_X, and NO_X). Shore-based power also called alternative maritime power or shore power can remarkably decrease the emission of air pollution or toxic substances to fulfill the environmental protection requirements [43]. For China, there are two issues deserving attention. Firstly, it would be helpful to establish supporting policies related to advance funds and research and development support to improve the standards for shore power technology in order to encourage cruise companies to take the initiative to renovate shore power facilities, to attract private high-tech enterprises to enter the onshore power industry by providing flexible preferential measures in qualification examination, capital loan acquisition, technology promotion, etc. In addition, the surveillance of air, soil pollution, water, and biodiversity of coastlines near ports should be strengthened. Particularly, before additional shore power facilities are introduced, clear guidance and a green cruise port evaluation model in line with China's situation should be established to track and detect relevant efficiency and performance. Further, the current study mainly focused on Chinese areas and lacks the generalization. To generalize the research study, the future research efforts may investigate non-ECA, outside of China, coastal control areas, inland river control areas, and different fuel types before and after the COVID-19 pandemic.

Data availability statement

Data will be made available on request.

Table 3
Comparison of cruise voyages at Xiamen Port Cruise Terminal in 2019.

	Xiamen Port Cruise Terminal*	This study	% Change
2019	136	150	10.29%

Note: The research team visited the Xiamen Port Cruise Terminal (Xiamen Cruise Home Port Group Heping Terminal Co., Ltd.) to conduct on-site research and obtain data on cruise voyages.

Table 4
Cruise changes in ECA and EEZ under different indicators in 2019 and 2020.

	2019			2020		
	ECA	EEZ	% Change	ECA	EEZ	% Change
Average ship number	18.5	19.33	4.50%	6.25	6.92	10.72%
Average GT	92974.10	96438.97	3.73%	71600.46	81387.01	13.67%
Average Power (kW)	53759.62	56010.35	4.19%	45848.66	49737.66	8.48%
Average Max Draught (m)	7.45	7.68	3.07%	7.85	7.93	0.95%
Average Design Speed (kn)	21.14	21.53	1.82%	23.64	23.42	−0.90%
AIS record	6597287	10326176	56.52%	1758626	2376163	35.11%
Average SOG (kn)	11.94	13.76	15.29%	3.51	5.19	47.88%
Total distance (nm)	211226.30	488840.90	131.43%	26771.50	78589.84	193.56%
Total time (days)	1830.23	2548.61	39.25%	1067.33	1216.09	13.94%
SO_x (tonnes)	359.39	7661.73	2031.90%	146.95	203.23	38.30%
NO_x (tonnes)	7543.92	16507.77	118.82%	2525.57	3858.76	52.79%
CO_2 (tonnes)	357415.90	782290.89	118.87%	141973.88	197974.83	39.44%
PM (tonnes)	127.46	1046.57	721.08%	47.67	69.66	46.13%
CO (tonnes)	348.29	694.95	99.53%	128.56	191.17	48.70%
CH_4 (tonnes)	3.50	10.08	188.31%	1.32	1.97	49.84%
N_2O (tonnes)	17.99	38.70	115.17%	7.04	9.97	41.59%
NMVOC (tonnes)	295.47	604.87	104.71%	99.94	157.99	58.08%
BC (tonnes)	38.88	115.37	196.76%	14.78	21.37	44.59%

CRediT authorship contribution statement

Qiong Chen: Writing – original draft, Conceptualization. **Yui-yip Lau:** Writing – review & editing, Data curation. **Maneerat Kanrak:** Supervision, Resources. **Xiaodong Sun:** Visualization, Data curation. **Pengfei Zhang:** Visualization, Data curation. **Yuk-Ming Tang:** Project administration, Investigation.

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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APPENDIX A

Table A.1
Fuel type in different regions.

Area		Year	Fuel type
Non-ECA		2019	HFO 2.5%
		2020	VLSFO 0.5%
China ECA	Coastal control area	2019	VLSFO 0.5%
		2020	VLSFO 0.5%
	Inland river control area	2019	VLSFO 0.5%
		2020	MGO 0.1%

References

[1] Y.-y. Lau, et al., Cruise terminals site selection process: an institutional analysis of the Kai Tak Cruise Terminal in Hong Kong, Research in Transportation Business & Management 13 (2014) 16–23.
[2] M. Ching-Pong Poo, Z. Yang, Y.-y. Lau, Vulnerability analysis of cruise shipping in ASEAN countries facing COVID-19 pandemic, Ocean Coast Manag. 248 (2024) 106919.
[3] X. Sun, et al., Cruisers' satisfaction with shore experience: an empirical study on a China-Japan itinerary, Ocean Coast Manag. 181 (2019) 104867.
[4] CLIA, Cruise Lines International Association (CLIA), Available at:, Cruise Industry Outlook [EB/OL], 2018 http://www.cruising.org. (Accessed 17 March 2023), 2018.
[5] X. Sun, et al., Shore excursions of cruise destinations: product categories, resource allocation, and regional differentiation, J. Destin. Market. Manag. 22 (2021) 100660.
[6] E.M. Osorio-Saez, N. Eryilmaz, A. Sandoval-Hernandez, Y.Y. Lau, E. Barahona, A.A. Bhatti, A. Zionts, Survey data on the impact of COVID-19 on parental engagement across 23 countries, Data Brief 35 (2021) 106813.
[7] Y.Y. Lau, M.A. Dulebenets, H.T. Yip, Y.M. Tang, Healthcare supply chain management under COVID-19 settings: the existing practices in Hong Kong and the United States, Healthcare 10 (8) (2022) 1549.
[8] Y.M. Tang, K.Y. Chau, W. Li, T.W. Wan, Forecasting economic recession through share price in the logistics industry with artificial intelligence (AI), Computation 8 (3) (2021) 70.
[9] Q. Wang, F. Zhang, What does the China's economic recovery after COVID-19 pandemic mean for the economic growth and energy consumption of other countries? J. Clean. Prod. 295 (2021) 126265.
[10] N. Ali, et al., Assessing the environmental impacts of COVID-19; A review, Pol. J. Environ. Stud. 30 (5) (2021) 4401–4403.
[11] Q. Chen, et al., Effects of COVID-19 on passenger shipping activities and emissions: empirical analysis of passenger ships in Danish waters, Marit. Pol. Manag. 50 (6) (2023) 776–796.
[12] H. Wang, Annual Report on China's Cruise Industry (2021), Social Sciences Academic Press, Beijing, 2021.
[13] H. Carić, Challenges and prospects of valuation – cruise ship pollution case, J. Clean. Prod. 111 (2016) 487–498.
[14] Q. Chen, et al., Interactions between Arctic passenger ship activities and emissions, Transport. Res. Transport Environ. 97 (2021) 102925.
[15] L. Zhen, et al., The effects of emission control area regulations on cruise shipping, Transport. Res. Transport Environ. 62 (2018) 47–63.
[16] Z. Wan, et al., Impact of emission control areas on atmospheric pollutant emissions from major ocean-going ships entering the Shanghai Port, China, Mar. Pollut. Bull. 142 (2019) 525–532.
[17] News and ZJOL, International cruise port shore power project is about to start, available at: http://cs.zjol.com.cn/kzl/202206/t20220610_24358378.shtml, 2022. (Accessed 14 September 2022).
[18] K. Wang, et al., Cruise shipping review: operations planning and research opportunities, Maritime Business Review 1 (2) (2016) 133–148.
[19] I. Vicente-Cera, et al., Use of AIS data for the environmental characterization of world cruise ship traffic, International Journal of Sustainable Transportation 14 (6) (2020) 465–474.
[20] O.J.A. Howitt, et al., Carbon emissions from international cruise ship passengers' travel to and from New Zealand, Energy Pol. 38 (5) (2010) 2552–2560.
[21] C. Walsh, A. Bows, Size matters: exploring the importance of vessel characteristics to inform estimates of shipping emissions, Appl. Energy 98 (2012) 128–137.
[22] A. Maragkogianni, S. Papaefthimiou, Evaluating the social cost of cruise ships air emissions in major ports of Greece, Transport. Res. Transport Environ. 36 (2015) 10–17.
[23] K. Poplawski, et al., Impact of cruise ship emissions in Victoria, BC, Canada, Atmos. Environ. 45 (4) (2011) 824–833.
[24] B. Dragović, et al., Ship emissions and their externalities in cruise ports, Transport. Res. Transport Environ. 61 (2018) 289–300.
[25] H. Carić, P. Mackelworth, Cruise tourism environmental impacts – the perspective from the Adriatic Sea, Ocean Coast Manag. 102 (2014) 350–363.
[26] J. Zheng, et al., A voyage with minimal fuel consumption for cruise ships, J. Clean. Prod. 215 (2019) 144–153.
[27] A. Fabregat, L. Vázquez, A. Vernet, Using Machine Learning to estimate the impact of ports and cruise ship traffic on urban air quality: the case of Barcelona, Environ. Model. Software 139 (2021) 104995.
[28] E. Tzannatos, Ship emissions and their externalities for the port of Piraeus – Greece, Atmos. Environ. 44 (3) (2010) 400–407.
[29] Q. Chen, et al., Capturing Effects of COVID-19 on Global Cruise Vessel Density and Emissions, SSRN, 2022.
[30] Q. Wang, et al., Underestimated impact of the COVID-19 on carbon emission reduction in developing countries – a novel assessment based on scenario analysis, Environ. Res. 204 (2022) 111990.
[31] M. Simonsen, S. Gössling, H.J. Walnum, Cruise ship emissions in Norwegian waters: a geographical analysis, J. Transport Geogr. 78 (2019) 87–97.
[32] R. Zhao, D. Wu, S. Patti, A bibliometric analysis of carbon labeling schemes in the period 2007–2019, Energies 13 (16) (2020) 4233.
[33] D. Xu, et al., The race to net-zero emissions: can green technological innovation and environmental regulation be the potential pathway to net-zero emissions? Technol. Soc. 75 (2023) 102364.
[34] BLM-Shipping, Available online: BLM-Shipping (2022) http://www.gogotrade.info/. (Accessed 3 March 2022).
[35] RightShip, RightShip, Available online: https://www.rightship.com/, 2021. (Accessed 1 July 2021).
[36] MarineTraffic, Available online: https://www.marinetraffic.com/, 2022. (Accessed 30 March 2022).
[37] China, Ministry of transport of the people's Republic of China, Available online: https://xxgk.mot.gov.cn/jigou/haishi/201812/t20181220_3146515.html/, 2022. (Accessed 30 March 2022), 2022.03.30].
[38] Marineregions, Marineregions, Available online: https://www.marineregions.org/eezsearch.php/, 2022. (Accessed 30 March 2022), 2022.03.30.
[39] United nations, available at: https://www.un.org/depts/los/LEGISLATIONANDTREATIES/PDFFILES/chn_1998_eez_act.pdf, 2023. (Accessed 5 March 2023).
[40] H. Liu, et al., Health and climate impacts of ocean-going vessels in East Asia, Nat. Clim. Change 6 (11) (2016) 1037–1041.
[41] B. Comer, N. Olmer, X. Mao, B. Roy, D. Rutherford, Prevalence of heavy fuel oil and black carbon in Arctic shipping, 2015 to 2025, Available online: https://theicct.org/sites/default/files/publications/HFO-Arctic_ICCT_Report_01052017_vF.pdf, 2017. (Accessed 25 March 2021).
[42] K. Cullinane, S. Cullinane, Chapter 3 - policy on reducing shipping emissions: implications for "green Ports"*, in: R. Bergqvist, J. Monios (Eds.), Green Ports, Elsevier, 2019, pp. 35–62.
[43] Y.-Y. Lau, X. Sun, Chapter 14 - an investigation into the responsibility of cruise tourism in China, in: A.K.Y. Ng, J. Monios, C. Jiang (Eds.), Maritime Transport and Regional Sustainability, Elsevier, 2020, pp. 239–249.