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# CO<sub>2</sub> emission and socioeconomic inventories of Guangdong-Hong Kong-Macao Greater Bay Area and surrounding cities 2000-2022

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The Guangdong-Hong Kong-Macao Greater Bay Area (GBA) is a leading economic region and a pilot demonstration region of carbon peaking in China. The city-level time-series CO<sub>2</sub> emission inventories of the GBA region are crucial for the formulation of policies on climate change mitigation pathways. However, the region lacked a consistent and comparable time-series city-level CO<sub>2</sub> emissions inventory dataset. In this study, we provided CO<sub>2</sub> emission and socioeconomic inventories of the GBA cities and their surrounding twelve Guangdong cities from 2000 to 2022. The CO<sub>2</sub> emission inventories were compiled by 47 economic sectors, 17 types of fossil fuels, and four industrial processes. The dataset provides temporal emissions estimates that support the design of regions' mitigation strategies, and help China achieve its goal of peaking carbon emissions before 2030.

## Background & Summary

Cities are responsible for over 70% of global carbon dioxide (CO<sub>2</sub>) emissions from energy consumption<sup>1</sup>, highlighting their critical importance in addressing climate change and emissions reduction. The Guangdong-Hong Kong-Macao Greater Bay Area (GBA) in southern China, featuring rapid urbanization and world-class city clusters, is at the forefront of promoting comprehensive green transition in economic and social development<sup>2,3</sup>. The GBA consists of nine Guangdong Province cities, Hong Kong, and Macao (Fig. 1). This region contributed 11% of the national Gross Domestic Product (GDP) in 2024 with only 0.58% of the territory and 6% of the population<sup>4</sup>. The other twelve Guangdong cities surrounding the GBA had close ties with the GBA cities in terms of industry and infrastructure<sup>5</sup>. In 2022, the GBA's GDP growth rate of 9.3% ranked first among the four globally prominent bay areas, followed by the New York Metropolitan Area (7.2%), the Tokyo Bay Area (3.5%), and the San Francisco Bay Area (3.3%)<sup>6-8</sup>. But the energy consumption per unit of GDP in GBA was higher than the three bay areas' average due to high economic growth<sup>9</sup>. With the continuous growth of population and economy, the energy consumption and resource pressure in GBA were expected to increase<sup>10</sup>. Adapting to global climate challenges, the Chinese government set ambitious goals to peak carbon emissions by 2030 and reach carbon neutrality by 2060, and the GBA was identified as one of the pilot demonstration regions for peaking carbon emissions and achieving carbon neutrality<sup>3</sup>. The GBA has taken measures to reduce CO<sub>2</sub> emissions, including replacing fossil fuels with clean energy and optimizing the industrial structure<sup>11</sup>.

Consistent, comparable, transparent, and time-series emission inventories are crucial for city-level decision-makers to assess the effectiveness of emission mitigation efforts and develop targeted climate action plans through identifying key emission sources. Existing studies have estimated CO<sub>2</sub> emissions of GBA but mainly focused on specific socioeconomic sectors, such as residential sector<sup>12</sup> and power generation<sup>13</sup>. Some studies focused on individual core cities<sup>14,15</sup> or specific years<sup>16-18</sup>, limiting the understanding of time-series variations in carbon emissions. The comparability of some cities' emission inventories is limited due to inconsistencies in accounting system boundaries and emission factor selections<sup>16,17,19-21</sup>. Some studies estimated city-level

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**Fig. 1** Geolocation of the Guangdong-Hong Kong-Macao Greater Bay Area and surrounding cities.

CO<sub>2</sub> emissions with proxy data (e.g., GDP, night-time light imagery, building morphology)<sup>12,15,19,21</sup>, which may overlook sectoral information that helps identify key emission contributors (Table 1).

Guangdong Province is the largest greenhouse gas (GHGs) emitter in southern China<sup>22,23</sup>, and CO<sub>2</sub> was identified as the key contributor (92%) of total GHGs<sup>24,25</sup>. The CO<sub>2</sub> emissions monitoring and urban climate change mitigation efforts were further elevated by the continuing urbanization and population growth in the region. This dataset provided comparable, transparent, and verifiable CO<sub>2</sub> emissions inventories for nine GBA cities and twelve surrounding cities. The inventories covered 17 types of fossil fuel and 47 socioeconomic sectors, which were consistent with China's national and provincial inventories.

The dataset supports the refinement of low-carbon strategies and the design of sustainable development policies at city-level. Consistent city-level emission estimates would facilitate multi-scale and inter-city carbon mitigation evaluation and comparative studies. Detailed sectoral and energy-specific emissions could be used for city-level studies focusing on mitigation pathways and related policy making.

## Methods

**Emission scope.** This study followed the Intergovernmental Panel on Climate Change (IPCC) guidance<sup>26</sup> to estimate in-boundary CO<sub>2</sub> emissions from fossil fuel combustion and industry processes of prefectural-level cities in Guangdong Province, 2000–2022. Seventeen types of fossil fuel consumption (Table 2), 47 socioeconomic sectors (Table 3), and four types of industrial processes were considered from the production side. The emissions from electricity and heat production are calculated through primary energy inputs, without considering imports outside the administrative territorial boundary. Energy losses from transport and transformation processes, or used as chemical raw material, were removed from energy consumption to avoid double-counting.

**Emission calculation and inventory construction.** This study constructed the CO<sub>2</sub> emission inventories based on a uniform carbon emission accounting framework (Fig. 2) proposed by our previous work<sup>27,28</sup>. This study considered 17 types of energy, which can generally be categorized as coal, oil, and natural gas (Table 2). The inventories also incorporated emissions from four key industrial processes, including the production of cement, coke as a reducing agent, ammonia, and lime, which together contribute more than 95% of China's process-related emissions<sup>29</sup>.

Energy-related CO<sub>2</sub> emissions (CE<sub>e</sub>) were calculated based on the mass balance of fossil fuel consumption converted to CO<sub>2</sub> emissions (Eq. 1).

$$CE_e = \sum AD \times EF = \sum_{i=1}^{17} \sum_{j=1}^{47} AD_{ij} \times NCV_j \times CC_j \times O_{ij} \quad (1)$$

Ref.	Case City	Emission scope	Emission calculation	Sector	Time-span
12	GBA and surrounding Guangdong cities	CO <sub>2</sub> emissions from in-boundary energy consumption, and imported electricity generation	Cities with energy balance table: sectoral approach, with emission factors collected from Shan <i>et al.</i> <sup>28</sup> ; Cities without energy balance table: downscaled from estimations with nighttime light data	Residence	2010, 2020
13	GBA cities	CO <sub>2</sub> emissions from energy consumption by electricity generation and purchased electricity	Emission factor method with emission factors collected from Ministry of Ecology and Environment <sup>51</sup>	Electricity generation	2020
14	Shenzhen	CO <sub>2</sub> emissions from energy consumption	Emission factor method, with emission factors collected from CDMC <sup>52</sup> , IPCC <sup>26</sup> , and South China Power grid	Public transport	2005–2015
15	Hong Kong	CO <sub>2</sub> emissions from energy consumption, electricity, and heating generation	Sectoral approach with emission factors collected from IPCC <sup>26</sup> , downscaled to 100m-grid with proxy data (transport network and building morphology)	Residence, business, industry, and transport	2016
16	305 Chinese cities (including GBA and surrounding Guangdong cities)	CO <sub>2</sub> , CH <sub>4</sub> , N <sub>2</sub> O, fluorinated GHGs from in-boundary energy consumption and industrial processes, and imported electricity (only CO <sub>2</sub> covered)	Sectoral approach, with emission factors collected from China Greenhouse Gas Inventory Research 2005 and 2008	CO <sub>2</sub> ; industry, transport, agriculture, service, household, industrial processes, indirect emissions from electricity generation, forestry carbon sequestration. (Covered sectors for CH <sub>4</sub> , N <sub>2</sub> O, and fluorinated GHGs omitted here)	2015
17	GBA and surrounding Guangdong cities	CO <sub>2</sub> emissions from energy consumption and industrial processes	Sectoral approach and reference approach, with emission factors collected from Liu <i>et al.</i> <sup>31</sup>	Industry, household, and industrial processes	2017
18	182 Chinese cities (including 12 Guangdong cities)	CO <sub>2</sub> emissions from energy consumption and industrial processes	Sectoral approach, with emission factors collected from Liu <i>et al.</i> <sup>31</sup>	47 socioeconomic sectors belonged to primary industry, manufacturing industry, construction, service, and household	2010
19	GBA cities	CO <sub>2</sub> emissions from impervious land (energy consumption) and cropland (fertilizers, machinery, agricultural film, and irrigation, CO <sub>2</sub> absorption excluded)	Impervious land: emission factor method, with emission factors collected from Mahony <sup>53</sup> and Yan <i>et al.</i> <sup>54</sup> , downscaled to 30m-grid with nighttime lighting; Cropland: emission factor method, with emission factors collected from Oak Ridge National Laboratory and Nanjing Agricultural University, downscaled to 30m-grid with NDVI data	Impervious land: residence and various production activities; Cropland: agricultural production	2001–2020
20	GBA and surrounding Guangdong cities	CO <sub>2</sub> emissions from in-boundary energy consumption and industrial process	Sectoral approach, with emission factors collected from Liu <i>et al.</i> <sup>31</sup>	agriculture, forestry, fishery and livestock, industry, construction, service, transportation, and residence	2000–2019
21	Guangdong cities	CO <sub>2</sub> emissions from energy consumption	Calculate-and-correct model, with emission factors collected from Wang <i>et al.</i> <sup>35</sup>	(Not specific)	2005–2017

**Table 1.** Previous studies on carbon dioxide emission accounting in the Greater Bay Area.

where,  $i$  and  $j$  denoted the energy types and socioeconomic sector, respectively;  $AD$  referred to the activity data (i.e., fossil fuel consumption);  $NCV_j$ ,  $CC_j$  and  $O_{ij}$  represented three emission factors ( $EF$ ), namely, net calorific value in the  $j^{th}$  sector, carbon content in the  $j^{th}$  sector, and oxygenation efficiency of  $i^{th}$  energy type in  $j^{th}$  sector. These emission factors were collected from our previous work<sup>30</sup> and listed in Table 2.

Process-related emissions ( $CE_p$ ) were produced during chemical reactions in industrial processes. They were estimated using Eq. 2.

$$CE_p = \sum_{t=1}^4 AD_t \times CE_t \quad (2)$$

where,  $AD_t$  and  $CE_t$  denoted the activity data (i.e., production of the industrial products) and the corresponding emission factor of industrial process of product  $t$ , respectively. The emission factor for cement and lime production were sourced from Liu *et al.*<sup>31</sup> and Shan *et al.*<sup>32</sup>, respectively, and the rest of the emission factors were sourced from IPCC<sup>26</sup>.

Activity data of fossil fuels were collected from the Energy Balance Tables (EBTs), which provided the transformation and final consumption of each fuel<sup>27,28,33</sup>. The EBTs for Guangzhou (2000–2013), Qingyuan (2005–2014), and Yangjiang (2006–2022) were collected from the city's statistical yearbooks<sup>34–36</sup>. For other cities and individual years without EBTs, Guangdong provincial EBTs sourced from national energy statistical yearbooks<sup>37</sup> were scaled down to the city-level by the city's share of the sector's GDP and population. Energy consumption data were missing in Dongguan (2000–2013), Jiangmen (2004), Shenzhen (2004, 2006, and 2007), Zhongshan (2004), and Zhuhai (2000), and their energy consumption data were derived from the industry's value-added from adjacent years. Due to data limitations, statistics from Hong Kong and Macao could not be included in this accounting framework. Emissions data for the two cities from 2000 to 2022 were sourced from the Emissions Database for Global Atmospheric Research (EDGAR) dataset version 8.0<sup>38–40</sup>, and appended as supplementary

Fuel types	$NCV_j$	$CC_i$
	$PJ/10^4 \text{ t}, 10^8 \text{ m}^3$	$\text{tC/TJ}$
Coal	Raw coal	0.21
	Cleaned coal	0.26
	Other washed coal	0.15
	Briquette	0.18
	Coke	0.28
	Coke over gas	1.61
	Other gas	0.83
	Other coking products	0.28
Oil	Crude oil	0.43
	Gasoline	0.44
	Kerosene	0.44
	Diesel oil	0.43
	Fuel oil	0.43
	Other petroleum products	0.51
	LPG	0.47
	Refinery gas	0.43
	Gas	3.89
	Nature gas	15.32

**Table 2.** Emission factors of fossil fuels.

references to ensure the completeness of the inventory. The EDGAR dataset and our inventories adhered to the IPCC guidelines for emission estimations.

**Socioeconomic data.** Data on population and GDP of 23 cities were collected from each city's statistical yearbook. Detailed sources could be found in our dataset at Figshare<sup>41</sup>. The carbon emissions per unit of GDP and per capita in the inventory are derived using the population and GDP data.

### Data Records

The datasets consisted of CO<sub>2</sub> emission inventories and socioeconomic data for the GBA and surrounding Guangdong cities, spanning from 2000 to 2022. The dataset has been made available at Figshare<sup>41</sup>. All inventories were organized in Microsoft Excel spreadsheets using a uniform structure. The carbon emission inventories were arranged as follows:

1. Summed CO<sub>2</sub> emissions year-by-year at the city level [“Emission inventory.xlsx”, in sheet “Overview”];
2. Detailed CO<sub>2</sub> emissions by 47 industry sectors [“Emission inventory.xlsx”, in sheet “CityEmission\_ByEnergy”] and by 17 energy types for each city [“Emission inventory.xlsx”, in sheet “CityEmission\_BySector”]. Detailed emission data for Dongguan (2000–2013), Shenzhen (2004, 2006, and 2007), Jiangmen (2004), Zhuhai (2000), and Zhongshan (2004) were unavailable due to limited data accessibility.

Apart from the emission inventories, the socioeconomic data were compiled as a reference for the users. To make the records comparable across the year, the constant price of 2022 was applied to estimate GDP in chained volume. They were arranged in a single Excel file and recorded as follows:

1. Year-end population at city-level, in 10 thousand person [“Socioeconomic data.xlsx”, in sheet “Population”];
2. GDP in chained (2022) volume at the city-level, in 100 million Renminbi (RMB) [“Socioeconomic data”, in sheet “Gross Domestic Product”];
3. Price deflators of GDP (year 2022 = 100) at the city level [“Socioeconomic data.xlsx”, in sheet “Gross Domestic Product”].

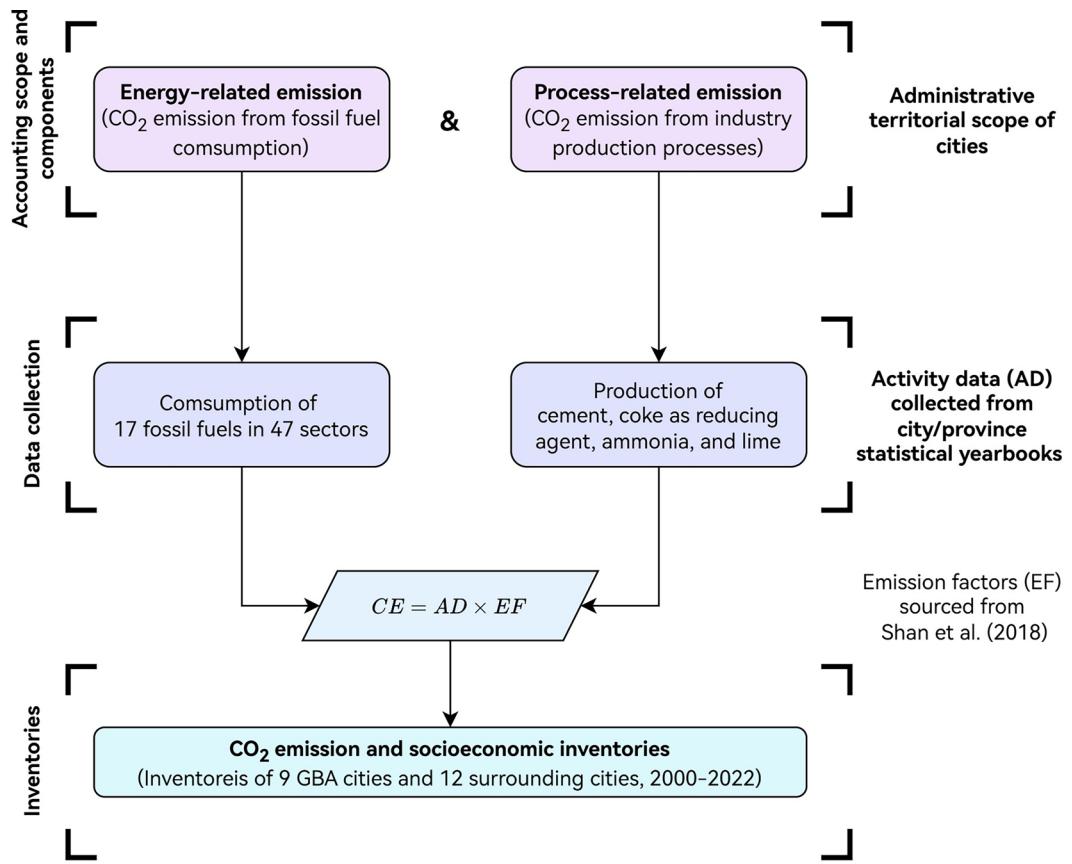
### Technical Validation

**Statistical analysis.** Figure 3a illustrated the temporal evolution of the emissions in the GBA and surrounding cities from 2000 to 2022. Over the 23-year period, the CO<sub>2</sub> emissions have increased at an average of 5.23% per year, reaching a maximum of 819 million tons in 2021. A rapid increase occurred during 2000–2007 with an annual growth rate of 9.65%, and surrounding cities grew 3.91% faster than GBA cities. Growth rates fluctuated after 2008 and slowed down to 2.97% after 2011. The slowdown in growth is attributed to fossil fuel reduction policies and technological innovations (e.g., clean energy promotion in energy production, industrial manufacture, transportation, and residence<sup>42</sup>), which lowered carbon intensity and emissions<sup>20</sup>. From 2020 to 2021, there was a 10.97% surge as energy demand rebounded following the COVID-19 pandemic, aligning with the national trend of economic recovery<sup>43,44</sup>.

Socioeconomic sectors	Category
Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy	Farming sector
Coal Mining and Dressing	
Petroleum and Natural Gas Extraction	
Ferrous Metals Mining and Dressing	
Nonferrous Metals Mining and Dressing	
Nonmetal Minerals Mining and Dressing	Energy production
Other Minerals Mining and Dressing	
Petroleum Processing and Coking	
Production and Supply of Electric Power, Steam and Hot Water	
Production and Supply of Gas	
Logging and Transport of Wood and Bamboo	
Food Processing	
Food Production	
Beverage Production	
Tobacco Processing	
Textile Industry	
Garments and Other Fiber Products	Light manufacturing
Leather, Furs, Down and Related Products	
Timber Processing, Bamboo, Cane, Palm Fiber & Straw Products	
Furniture Manufacturing	
Papermaking and Paper Products	
Printing and Record Medium Reproduction	
Cultural, Educational and Sports Articles	
Medical and Pharmaceutical Products	Manufacturing industries
Raw Chemical Materials and Chemical Products	
Chemical Fiber	
Rubber Products	
Plastic Products	
Nonmetal Mineral Products	
Smelting and Pressing of Ferrous Metals	
Smelting and Pressing of Nonferrous Metals	Heavy manufacturing
Metal Products	
Ordinary Machinery	
Equipment for Special Purposes	
Transportation Equipment	
Production and Supply of Electric Power, Steam and Hot Water	
Electric Equipment and Machinery	
Electronic and Telecommunications Equipment	
Instruments, Meters, Cultural and Office Machinery	High-tech industry
Other Manufacturing Industry	
Scrap and waste	
Construction	Construction
Transportation, Storage, Post and Telecommunication Services	
Wholesale, Retail Trade and Catering Services	Services sectors
Others	
Urban	
Rural	Residential usage

**Table 3.** Socioeconomics sectors and category.

During the period 2000–2022, the average emission intensity (ratio of total CO<sub>2</sub> emissions to GDP) of GBA cities dropped from 0.24 to 0.10 t/10<sup>4</sup> CNY (Fig. 3c). In terms of per capita CO<sub>2</sub> emissions (Fig. 3d), eight cities (i.e., Qingyuan, Foshan, Guangzhou, Hong Kong, Shenzhen, Meizhou, Yunfu, and Zhongshan) showed decreasing trends from 2010 to 2022, but the average of GBA and surrounding cities increased from 4.91 to 5.13 t/capita. Despite the overall increasing trend, 12 cities that accounted for 62% region's population had per capita CO<sub>2</sub> emissions in 2022 lower than the European Union average (6.1 t/capita<sup>45</sup>). In comparison with other global bay areas (Fig. 3b), the GBA had the highest total emissions but the lowest per capita emissions. The 2022 emission intensity of GBA (396 t/10<sup>6</sup>USD) was comparable to that of the San Francisco Bay Area (331 t/10<sup>6</sup>USD<sup>4,46</sup>), as high-tech industries and service sectors dominated both bay areas<sup>4,47</sup>. These patterns were consistent with

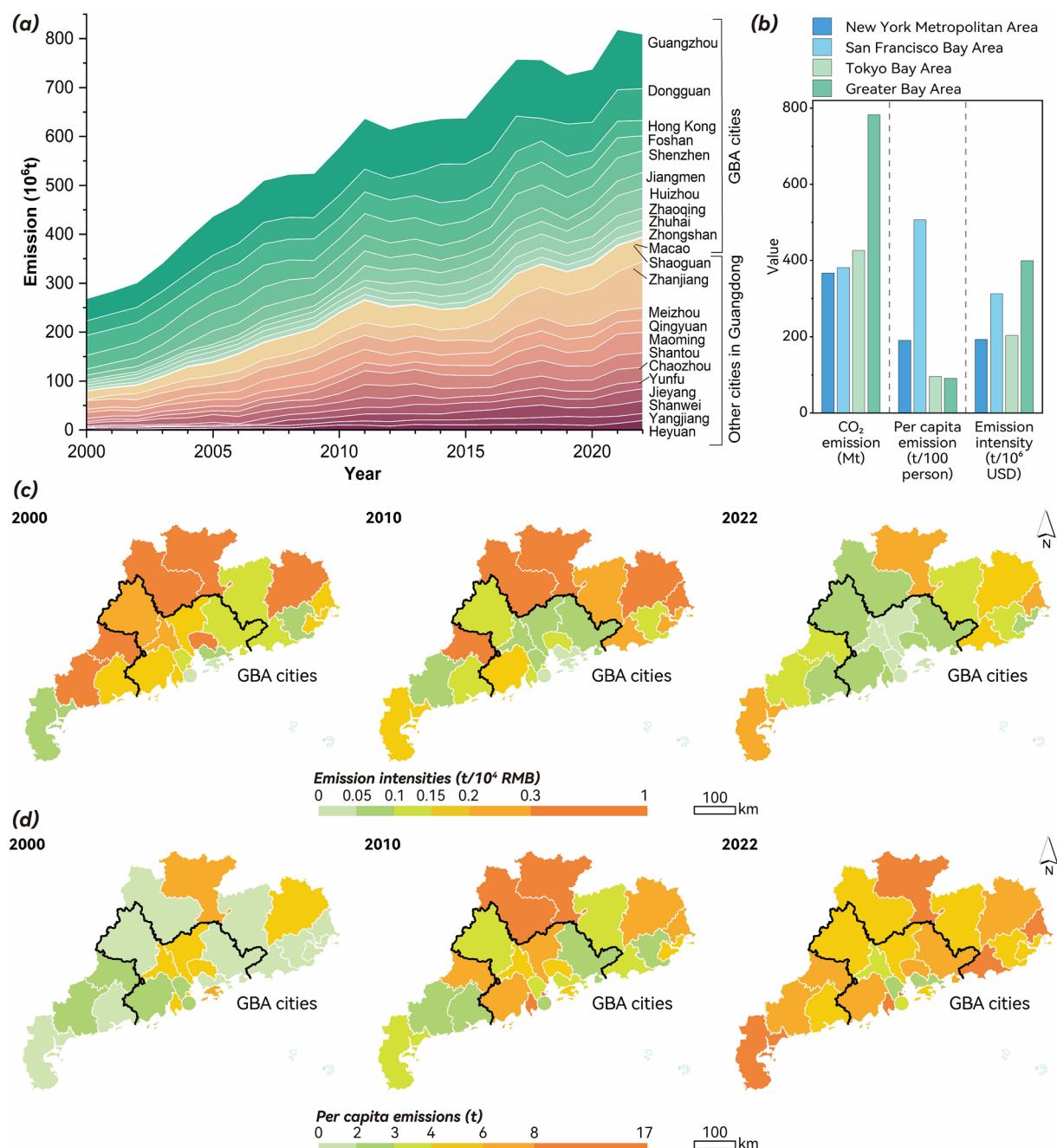


**Fig. 2** Diagram of CO<sub>2</sub> emission inventories construction for GBA and surrounding cities.

previous findings that GBA and the surrounding cities had made carbon decoupling progress through improving energy efficiency and industrial structure<sup>48</sup>, thus demonstrating the robustness of these inventories.

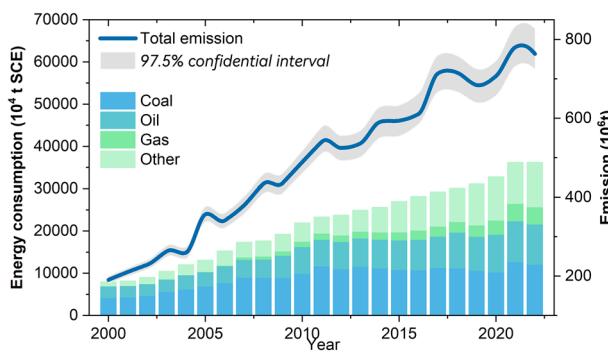
**Uncertainties.** The uncertainties of the inventories were mainly introduced from the activity data and emission factors<sup>49,50</sup>. Industrial process-related carbon emissions were not considered due to their relatively small share of total emissions (<9%) and usually have low uncertainty<sup>28,31</sup>. Uncertainties in energy-related carbon emissions were calculated using the Monte Carlo method recommended by the IPCC<sup>26</sup>. Due to data limitations, we assumed that both fossil fuel consumption and emission factors followed normal distributions, and coefficient of variation (CV, defined as the standard deviation divided by the mean) was set to 0.03 for coal, 0.01 for oil, and 0.02 for natural gas, and fossil fuel consumption have CV ranged from 5% to 30% depending on the sector<sup>31</sup>. Assuming both the fossil fuel consumption data and emission factors followed normal distributions<sup>31</sup>, their uncertainties were evaluated through 20,000 simulations, and a 97.5% confidence interval was estimated. The annual uncertainties of the CO<sub>2</sub> emission estimations laid within the interval of [-13.07%, 13.07%] (Fig. 4). The largest uncertainty was observed from Shantou in 2018 ([-10.53%, 10.53%]), while the smallest uncertainty was from Chaozhou in 2000 ([-0.64%, 0.64%]).

**Comparison with existing work.** Publicly available datasets on city-level carbon dioxide emissions for the GBA and surrounding Guangdong cities are currently rare. We collected comparable emission estimates for this area from existing literature to facilitate data comparison (Table 4). Shan *et al.*<sup>18</sup>, Luo *et al.*<sup>20</sup>, and Lin *et al.*<sup>17</sup> employed the sectoral approach to estimate carbon dioxide emissions in Guangdong at the city level. The total emissions from Luo *et al.* are close to our estimations, with a gap ranging between 19.2% (2017) and 0.6% (2009). CO<sub>2</sub> emissions for Guangzhou, Shenzhen, Zhuhai, and Shantou from Shan *et al.* were very close to our estimations, with a range from 1.86% to 4.12%. Variance existed in cities reliant on energy and the manufacturing sectors (e.g., Shaoguan, Maoming, Yangjiang, and Huizhou). The quality of activity data for these cities causes these variances. This study has updated the activity data based on the latest available statistical releases. Complete energy balance tables and detailed statistical data beyond major cities are essential for accurate emissions estimation. Lin *et al.* provided 2017 emissions for 21 Guangdong cities, categorized by energy consumption, industrial processes, and household energy use. While differences in sectoral categorization hindered direct comparisons at the sectoral level, total emissions of most cities are consistent with our 2017 inventory results, except for Guangzhou, Dongguan, Shenzhen, Yangjiang, and Maoming (>25% difference). Our estimations updated emission factors to cover 17 energy sources, while Lin *et al.* only considered coal, oil, and natural gas. This disparity may contribute to the differences.



**Fig. 3** CO<sub>2</sub> emissions of GBA and surrounding cities. **(a)** CO<sub>2</sub> emission trend 2000–2022; **(b)** comparison of socioeconomic emissions across global bay areas; **(c)** CO<sub>2</sub> emission intensity; **(d)** CO<sub>2</sub> emissions per capita. Note that Macao is enlarged in size to make it visible on maps in **(c)** and **(d)**.

**Limitations and future work.** Our inventories have some limitations that may lead to uncertainty. (1) Hong Kong and Macao could not be directly incorporated into the accounting framework. Future work will leverage bottom-up statistical data and calibrated general observations (e.g., satellite imagery) to provide more accurate CO<sub>2</sub> emission estimates for these cities. (2) Renewable energies (e.g., solar power, wind power, and hydro-power) were assumed as zero-carbon energy sources in this study, and the emissions from manufacturing are excluded. Indirect emissions along the supply chain will be incorporated. (3) This dataset only covers CO<sub>2</sub> emissions. Agricultural production is the prominent contributor to non-CO<sub>2</sub> greenhouse gases (e.g., CH<sub>4</sub> and N<sub>2</sub>O). More efforts are needed to incorporate non-CO<sub>2</sub> greenhouse gases into the accounting framework by leveraging process-based models and the satellite-based inversion method.



**Fig. 4** Energy consumption and total CO<sub>2</sub> emissions in GBA and surrounding cities, 2000–2022.

City-by-city comparison with Shan <i>et al.</i> and Lin <i>et al.</i> (Totals of cities)							Year-by-year comparison with Luo <i>et al.</i> (Totals of GBA and surrounding Guangdong cities)			
City	This dataset (2010)	Shan <i>et al.</i> (2010)	RPD *	This dataset (2017)	Lin <i>et al.</i> (2017)	RPD *	Year	This dataset	Luo <i>et al.</i> **	RPD *
Guangzhou	98.65	100.50	1.86%	116.2	65.3	56.1%	2000	268.5	252.6	6.1%
Dongguan	47.00	—	—	72.0	43.5	49.4%	2001	283.7	265.4	6.7%
Foshan	37.55	—	—	43.9	48.1	9.2%	2002	301.2	287.1	4.8%
Shenzhen	37.09	38.65	4.12%	49.7	31.3	45.6%	2003	340.9	321.5	5.9%
Jiangmen	26.79	30.94	14.39%	25.4	26.4	3.9%	2004	391.1	361.1	8.0%
Huizhou	11.76	23.59	66.91%	26.1	29.9	13.5%	2005	436.8	407.0	7.1%
Zhaoqing	14.33	—	—	28.3	22.3	23.8%	2006	463.3	444.0	4.3%
Zhuhai	12.76	13.00	1.91%	19.0	17.3	9.5%	2007	509.8	484.8	5.0%
Zhongshan	10.12	17.21	51.87%	14.0	11.3	21.8%	2008	522.3	492.5	5.9%
Shaoguan	39.96	22.73	54.99%	46.7	59.7	24.3%	2009	524.8	521.9	0.6%
Zhanjiang	24.48	—	—	60.4	48.3	22.4%	2010	578.3	566.5	2.1%
Meizhou	29.41	—	—	22.7	21.9	3.6%	2011	636.9	604.8	5.2%
Qingyuan	31.81	—	—	29.3	25.9	12.2%	2012	615.0	585.6	4.9%
Maoming	14.75	27.80	61.34%	28.2	18.5	41.5%	2013	628.3	570.3	9.7%
Shantou	24.85	24.43	1.70%	28.5	23.7	18.3%	2014	636.7	574.2	10.3%
Chaozhou	17.26	—	—	24.0	20.1	17.7%	2015	638.0	586.9	8.3%
Yunfu	16.02	17.86	10.90%	14.1	13.0	7.6%	2016	699.2	602.2	14.9%
Jieyang	13.58	—	—	17.4	17.3	1.0%	2017	757.6	625.2	19.1%
Shanwei	10.18	—	—	23.4	21.9	6.8%	2018	756.8	632.9	17.8%
Yangjiang	7.13	15.83	75.85%	12.4	25.1	67.9%	2019	726.3	625.2	15.0%
Heyuan	10.15	9.41	7.55%	11.4	13.2	14.7%				

**Table 4.** Comparisons of emission accounting results with existing works. \*RPD (Relative Percentage Difference) was calculated using the formula:  $RPD = |x_1 - x_2| / \left( \frac{x_1 + x_2}{2} \right)$ , where  $x_1$  and  $x_2$  denote the values being compared. \*\*The data were digitized from Figure 5a of Luo *et al.* due to the unavailability of raw/tabulated data from the original study.

## Data availability

The dataset is available at Figshare<sup>41</sup> (<https://doi.org/10.6084/m9.figshare.28235681>).

## Code availability

The MATLAB codes used to generate the emissions inventories are published in the Supplementary Information section of our previous work<sup>18</sup>.

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## References

- IEA (International Energy Agency). *Cities, Towns and Renewable Energy*. <https://doi.org/10.1787/9789264076884-en> (2009).
- General Office of the State Council. *Outline Development Plan for the Guangdong-Hong Kong-Macao Greater Bay Area*. (2019).
- National Development and Reform Commission. *Action Plan for Carbon Dioxide Peaking Before 2030*. (2021).
- HKTDC (Hong Kong Trade Development Council). Statistics of the Guangdong-Hong Kong-Macao Greater Bay Area. <https://research.hktdc.com/en/article/MzYzMDE5NzQ5>.
- Qian, Y. *et al.* Large inter-city inequality in consumption-based CO<sub>2</sub> emissions for China's Pearl River Basin cities. *Resour. Conserv. Recycl.* **176**, 105923 (2022).

6. Guangdong Statistics Bureau. *Guangdong Statistical Yearbook 2022-2023*. (China Statistics Press, 2022-2023).
7. Statistics Bureau of Japan. *Statistical Observations of Prefectures 2021-2022*. (Statistics Bureau of Japan).
8. U.S. Bureau of Economic Analysis. CAGDP2 gross domestic product (GDP) by county and metropolitan area 2021-2022. U.S. Bureau of Economic Analysis.
9. Lei, Y. *et al.* Spatiotemporal trajectory of energy efficiency in the Guangdong-Hong Kong-Macao Greater Bay Area and implications on the route of economic transformation. *PLOS One* **19**, e0307839 (2024).
10. Wu, M., Wu, J. & Zang, C. A comprehensive evaluation of the eco-carrying capacity and green economy in the Guangdong-Hong Kong-Macao Greater Bay Area, China. *J. Cleaner Prod.* **281**, 124945 (2021).
11. People's Government of Guangdong Province. Guangdong Carbon Peak Implementation Plan. [https://www.gd.gov.cn/zwjk/wjk/qbwj/yf/content/post\\_4091117.html](https://www.gd.gov.cn/zwjk/wjk/qbwj/yf/content/post_4091117.html).
12. Chen, L. *et al.* The impact of energy metabolic pattern on household carbon emissions: a spatio-temporal perspective in Guangdong-Hong Kong-Macao Greater Bay Area. *Sustainable Cities Soc.* **119**, 106094 (2025).
13. Xu, M. *et al.* LEAP model-based analysis to low-carbon transformation path in the power sector: a case study of Guangdong-Hong Kong, Macao Greater Bay Area. *Sci. Rep.* **14**, 7405 (2024).
14. Dong, D. *et al.* Towards a low carbon transition of urban public transport in megacities: a case study of Shenzhen, China. *Resour. Conserv. Recycl.* **134**, 149–155 (2018).
15. Cai, M., Shi, Y. & Ren, C. Developing a high-resolution emission inventory tool for low-carbon city management using hybrid method - a pilot test in high-density Hong Kong. *Energy Build.* **226**, 110376 (2020).
16. Cai, B. *et al.* China city-level greenhouse gas emissions inventory in 2015 and uncertainty analysis. *Appl. Energy* **253**, 113579 (2019).
17. Lin, B. & Li, Z. Spatial analysis of mainland cities' carbon emissions of and around Guangdong-Hong Kong-Macao Greater Bay Area. *Sustainable Cities Soc.* **61**, 102299 (2020).
18. Shan, Y., Liu, J., Liu, Z., Shao, S. & Guan, D. An emissions-socioeconomic inventory of Chinese cities. *Sci Data* **6**, 190027 (2019).
19. Cai, Y. *et al.* Quantifying high-resolution carbon emissions driven by land use change in the Guangdong-Hong Kong-Macao Greater Bay Area. *Urban Clim.* **55**, 101943 (2024).
20. Luo, X., Liu, C. & Zhao, H. Driving factors and emission reduction scenarios analysis of CO<sub>2</sub> emissions in Guangdong-Hong Kong-Macao Greater Bay Area and surrounding cities based on LMDI and system dynamics. *Sci. Total Environ.* **870**, 161966 (2023).
21. Wang, W., Wang, W., Xie, P. & Zhao, D. Spatial and temporal disparities of carbon emissions and interregional carbon compensation in major function-oriented zones: a case study of Guangdong province. *J. Cleaner Prod.* **245**, 118873 (2020).
22. Liu, Z., Geng, Y., Lindner, S. & Guan, D. Uncovering China's greenhouse gas emission from regional and sectoral perspectives. *Energy* **45**, 1059–1068 (2012).
23. European Commission, Joint Research Centre & Agency, I. E. EDGAR community GHG database: IEA-EDGAR CO<sub>2</sub>, EDGAR CH<sub>4</sub>, EDGAR N<sub>2</sub>O, EDGAR F-GASES version 2024. European Commission, JRC (2024).
24. Qing, L. *et al.* High Resolution Emission Inventory of Greenhouse Gas and Its Characteristics in Guangdong, China. *Environ. Sci.* **45**, 909–919 (2024).
25. Ministry of Ecology and Environment. *Fourth Biennial Update Report on Climate Change of People's Republic of China*. <https://unfccc.int/sites/default/files/resource/The%20People%20%80%99s%20Republic%20of%20China%20Fourth%20Biennial%20Update%20Report%20on%20Climate%20Change.pdf> (2024).
26. Intergovernmental Panel on Climate Change. Guidelines for national greenhouse gas inventories. (2006).
27. Zhou, Y., Shan, Y., Liu, G. & Guan, D. Emissions and low-carbon development in Guangdong-Hong Kong-Macao Greater Bay Area cities and their surroundings. *Appl. Energy* **228**, 1683–1692 (2018).
28. Shan, Y. *et al.* Methodology and applications of city level CO<sub>2</sub> emission accounts in China. *J. Cleaner Prod.* **161**, 1215–1225 (2017).
29. National Development and Reform Commission. The people's republic of China second national communication on climate change. <http://qhs.mee.gov.cn/kzwsqtpf/20190>.
30. Shan, Y. *et al.* China CO<sub>2</sub> emission accounts 1997–2015. *Sci. Data* **5**, 170201 (2018).
31. Liu, Z. *et al.* Reduced carbon emission estimates from fossil fuel combustion and cement production in China. *Nature* **524**, 335–338 (2015).
32. Shan, Y., Liu, Z. & Guan, D. CO<sub>2</sub> emissions from China's lime industry. *Appl. Energy* **166**, 245–252 (2016).
33. Zhou, Y. *et al.* Trends, drivers, and mitigation of CO<sub>2</sub> emissions in the Guangdong-Hong Kong-Macao greater bay area. *Engineering* **23**, 138–148 (2023).
34. Guangzhou Municipal Statistics Bureau. *Guangzhou Statistical Yearbook 2001–2023*. (China Statistics Press, 2001–2023).
35. Qingyuan Municipal Statistics Bureau. *Qingyuan Statistical Yearbook 2001–2023*. (China Statistics Press, 2001–2023).
36. Yangjiang Municipal Statistics Bureau. *Yangjiang Statistical Yearbook 2001–2023*. (China Statistics Press, 2001–2023).
37. National Bureau of Statistics Department of Energy Statistics. *China Energy Statistical Yearbook 2000–2023*. (China Statistics Press, Beijing).
38. Crippa, M. *et al.* GHG Emissions of All World Countries. <https://doi.org/10.2760/953322> (Publications Office of the European Union, Luxembourg, 2023).
39. Crippa, M. *et al.* EDGAR v8.0 greenhouse gas emissions. European Commission, Joint Research Centre (JRC) <https://doi.org/10.2905/b54d8149-2864-4fb9-96b9-5fd3a020c224> (2023).
40. IEA-EDGAR CO<sub>2</sub>. IEA-EDGAR CO<sub>2</sub>: a component of the EDGAR (emissions database for global atmospheric research) community GHG database version 8.0. *International Energy Agency (IEA)* <http://www.iea.org/data-and-statistics> (2023).
41. Y Zhou *et al.* CO<sub>2</sub> emission and socioeconomic inventories of Guangdong-Hong Kong-Macao Greater Bay Area and surrounding cities 2000–2022. *figshare* <https://doi.org/10.6084/m9.figshare.28235681>.
42. People's Government of Guangdong Province. The 12th five-year plan for energy development of Guangdong province. <https://drc.gd.gov.cn/attachements/2019/01/09/6707534c42968bd40ddb4b41c3c5565.pdf> (2011).
43. Xu, J., Guan, Y., Oldfield, J., Guan, D. & Shan, Y. China carbon emission accounts 2020–2021. *Appl. Energy* **360**, 122837 (2024).
44. Jiang, P., Fan, Y. V. & Klemeš, J. J. Impacts of COVID-19 on energy demand and consumption: challenges, lessons and emerging opportunities. *Appl. Energy* **285**, 116441 (2021).
45. Ritchie, H., Rosado, P. & Roser, M. CO<sub>2</sub> emissions per capita, in CO<sub>2</sub> and greenhouse gas emissions. <https://archive.ourworldindata.org/20250718-083422/grapher/co-emissions-per-capita.html> (2025).
46. City and County of San Francisco. San Francisco's annual greenhouse gas emissions. <https://www.sf.gov/data-greenhouse-gas-emissions>.
47. Guangzhou Municipal Statistics Bureau. Guangzhou Statistical Yearbook 2023. [http://tjj.gz.gov.cn/datav/admin/home/www\\_nj/2022/index.html](http://tjj.gz.gov.cn/datav/admin/home/www_nj/2022/index.html) (2023).
48. Yang, Z., Zhou, J., Zhu, H. & Wang, S. Decoupling and decomposition of emissions and economic growth in Guangdong: a perspective of embodied carbon flow. *J. Cleaner Prod.* **459**, 142518 (2024).
49. Shan, Y. *et al.* City-level climate change mitigation in China. *Sci. Adv.* **4**, eaaoq0390 (2018).
50. Guan, D., Liu, Z., Geng, Y., Lindner, S. & Hubacek, K. The gigatonne gap in China's carbon dioxide inventories. *Nat. Clim. Change* **2**, 672–675 (2012).
51. Ministry of Ecology and Environment. 2019 Annual Emission Reduction Project of China's Regional Power Grid Baseline Emission Factors. [https://www.mee.gov.cn/ywzg/ydqhbh/wsqtkz/202012/t20201229\\_815386.shtml](https://www.mee.gov.cn/ywzg/ydqhbh/wsqtkz/202012/t20201229_815386.shtml) (2020).
52. Clean Development Mechanism in China. China regional grid baseline emission factor (2007–2014) (2007).

53. Mahony, T. O. Decomposition of Ireland's carbon emissions from 1990 to 2010: an extended kaya identity. *Energy Policy* **59**, 573–581 (2013).
54. Yan, H., Guo, X., Zhao, S. & Yang, H. Variation of net carbon emissions from land use change in the beijing-tianjin-hebei region during 1990–2020. *Land* **11**, 997 (2022).
55. Wang, W., Kuang, Y. & Huang, N. Study on the decomposition of factors affecting energy-related carbon emissions in guangdong province, china. *Energies* **4**, 2249–2272 (2011).

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### Author contributions

Y.Z. led the project and provided the methods. P.L. calculated and verified the dataset with support from Y.S. Y.Z., P.L. and A.G., collected the raw data and programmed the calculation steps. Y.Z., P.L., A.G., Y.S., D.G. and Z.Y contributed to the writing and revision of the manuscript.

### Competing interests

The authors declare no competing interests.

### Additional information

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