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High spatio-temporal heterogeneity of carbon footprints in the Zhejiang Province, China, from 2005 to 2015: implications for climate change policies

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Abstract
Energy consumption is a major factor influencing climate change. Low-carbon strategies can be defined from carbon (C) footprint and ecological pressure caused by energy consumption. We hypothesized that this should be done at the regional and city levels because factors controlling C footprints vary with location and time, yet there is actually little knowledge at local levels. Here, we mapped the C emissions and footprint of 11 cities in the Zhejiang Province of China, a rapidly growing area of about 57 million inhabitants, which is representative of the strong economic growth in China. The C footprint is expressed as the land surface necessary to adsorb C emissions. We studied spatio-temporal evolution of C footprints from 2005 to 2015 using the center of gravity method. Results show that total annual C emissions due to energy consumption in Zhejiang increased by 40.83 million tons (55.8%) from 2005 to 2011. Then, from 2011 to 2015, C emissions decreased by 5.8%, which is explained by the 5-year national plan aiming at decreasing emissions. Similarly, the total C footprint increased by 55.8% from 29,201,904 hm^2 in 2005 to 45,496,817 hm^2 in 2011 and then declined by 5.8% from 2011 to 2015. At the city level, Ningbo has the largest C footprint contribution, whereas Lishui the lowest. Zhoushan shows an increase in C emissions and footprint, whereas Hangzhou and Shaoxing show a decline. The center of gravity of the C footprint is located in Shaoxing and is moving southeast from 2006 to 2011. Overall, our findings reveal the high spatial heterogeneity of C footprint at the regional and city levels, implying that national low-carbon strategies should be adapted at lower levels for higher efficiency.

Keywords Spatio-temporal heterogeneity · Energy consumption · Carbon footprint · Zhejiang Province

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Introduction

Carbon emissions from energy consumption are highly influencing climate change and global warming (Chuai et al. 2012; Gregg et al. 2008). According to the fifth report of the Intergovernmental Panel on Climate Change (IPCC), more than 50% of the increase in the mean surface temperature of the Earth is due to anthropic emissions from 1951 to 2010. During this time period, the 0.5–1.3 °C increase is attributed to greenhouse gas emissions (Myhre et al. 2013). Since 2007, China has surpassed the USA as the world's largest carbon emitter (Shi et al. 2019). China relies heavily on fossil fuels, which is not a sustainable energy source, to keep its economy growth (Musa et al. 2018). In order to reduce the carbon intensity of its economy by 40–45% during 2005–2020 (Guan et al. 2014), China has promoted the development of renewable energies. In addition, a low-carbon, clean and modern energy system has been established by the Thirteenth Five-Year Plan for economic and social

development (2016–2020). In this context, strengthening carbon capture and storage technologies should reduce the amount of C emissions to the atmosphere, thus mitigating global warming (Su et al. 2016; Zhang et al. 2020).

The ecological footprint measures ecological assets and represents the area of biologically productive land and sea necessary for human consumptions and associated waste assimilation (Rees 1992). The C footprint is directly related to the ecological footprint. The C footprint is a measure of the total amount of carbon dioxide (CO_2) and methane emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest (Wright et al. 2011). The C footprint is calculated to estimate the impact of growing anthropogenic activities on the environment, to analyze climate change and to measure the intensity of C emissions (Chu et al. 2018; Ding et al. 2018; Guo et al. 2018). The C footprint is studied at several scales, including individuals, household, organizations, cities, provinces and countries.

Chuai et al. (2012) found pronounced increases in the C footprint due to the rapid increase in C emissions and less increasing area of productive land in different regions of China during 1999–2008. The highest C footprint was observed in Northern China, while the lowest in Southwest China, which is consistent with the findings of Wang et al. (2014). Furthermore, due to the pronounced differences in modern technology, consumption levels and economic growth, the C emissions among 30 provinces in mainland show a clear contrast (Feng et al. 2013). The major contribution to total C emissions comes from Eastern coastal regions, Zhejiang and Shandong Provinces (Zhang et al. 2014). In Zhejiang Province, industrialization and urbanization have increased in recent years. Efforts are being made to carry out C emissions inventories at the province level by the National Development and Reform Commission. The rate of C emissions caused by energy and chemical consumptions increased from 1997 to 2007, becoming the primary source of C emissions (Dong et al. 2013). The reduction in CO_2 intensity was 19% in Zhejiang Province during the Twelfth Five-Year Plan, from 2011 to 2015 (Yan et al. 2019).

Knowledge of spatio-temporal distributions of C emissions is important to understand the laws and mechanisms of C emissions and their cycles and to formulate policies. Nonetheless, the research on C emissions and C footprint in Zhejiang Province has mainly taken into account total changes (Dong et al. 2013; Du et al. 2012; Wang et al. 2014). Yet C emissions and footprints may vary at the local level. Therefore, we analyze here in detail the spatio-temporal changes of the C footprint during 2005–2015.

Experimental

Study area

Our study area is located in the southeast coastal region of China, in the southern region of the Yangtze River Delta (Fig. 1a). Zhejiang Province covers a total land area of 105,500 km^2, including 70.4% of mountainous and hilly

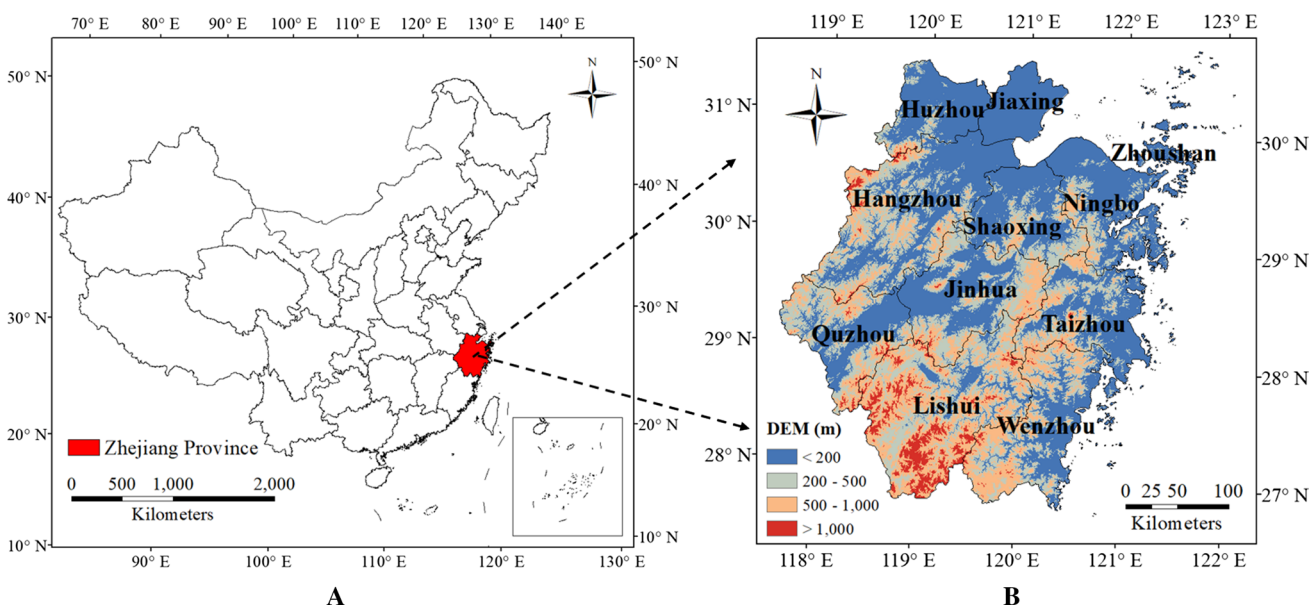

Fig. 1 **a** Geographical location of Zhejiang Province in China; **b** eleven prefecture-level cities and digital elevation model (DEM) in Zhejiang Province

lands. In 2017, its gross domestic product (GDP) was CN¥5.18 trillion, approximately US$757 billion, accounting for 6.26% of the total GDP of mainland China, ranking fourth among provinces. The fast economic growth has led to drastic changes in land use. Large amount of ecological land has been converted into construction land, including industrial, residential and commercial areas (Lin et al. 2017), thus increasing C emissions (Yang et al. 2018). There are eleven prefecture-level cities in Zhejiang Province: Hangzhou, Ningbo, Wenzhou, Jiaxing, Huzhou, Shaoxing, Jinhua, Quzhou, Zhoushan, Taizhou and Lishui (Fig. 1b). The terrain of the study area (Fig. 1b) has varying elevations in the southwest to the northeast, with mountains in the southwest, hills in the middle and flatland in the northeast.

Data sources

Energy sources include fossil fuels, biomass and renewable energy. Fossil fuels are one of the largest sources of C emissions in China. Here, we have considered C emissions and C footprint from fossil fuels including coal and coke, kerosene, gasoline, crude oil, fuel oil, diesel and liquefied petroleum gas. Data from fossil fuels and land use in 2005–2015 were included. Fossil fuel data were obtained from China City Statistical Yearbooks (https://data.cnki.net/Home/Index). Land use data, including forest and grass, were acquired from the Ministry of Natural Resources of the People's Republic of China.

Carbon emissions from energy consumption

We have computed C emissions, C footprint, C ecological capacity and C ecological deficit. The C emissions from major energy consumptions in Zhejiang Province are calculated from the following energy-related carbon emission model (IPCC 2006):

$$\mathrm{CE} = \sum \mathrm{C}_t = \sum M_t V_t E_t \tag{1}$$

where CE refers to the total C emissions caused by fossil energy consumptions in tons. C_t is the C emissions due to fossil energy type t (in tons). M_t denotes the amount of the fossil energy consumption belonging to type t (in tons). V_t depicts the standard coal coefficient of fossil energy belonging to type t. Standard coal equivalent (SCE) is adopted as the measurement unit for converting all fossil energy data. The standard coal coefficient is 0.7143 tSCE/t for coal, 0.9714 tSCE/t for coke, 1.4286 tSCE/t for oil and 1.33 kgSCE/m^3 for nature gas. E_t is the C emission coefficient of type t fossil energy. We classified these fossil energies into three categories: coal, oil, and natural gas, and we adopted their C emission coefficients from the Energy Research Institute National Development and Reform Commission (Wang and Zhu 2016): 0.7476 tC/tSCE for coal, 0.5825 tC/tSCE for oil and 0.4435 tC/tSCE for natural gas. The unit tC/tSCE represents C emissions, in tons, from one standard coal equivalent, in tons.

Carbon footprint

Plant photosynthesis was considered as the only component able to indicate the carbon sink of terrestrial ecosystems. In China, both forests and grasslands serve as major carbon sink (Piao et al. 2009; Zhang et al. 2015). The ratio of carbon absorbed by forests and grasslands is 82.72/17.28 (Xie et al. 2008): Out of one ton of carbon, 0.8272 ton is absorbed by the forests and 0.1728 ton is absorbed by the grasslands. During harvest, most of the carbon stored in agricultural vegetation is released to the atmosphere in a short time (Fang et al. 2007). Thus, the carbon sink from agricultural vegetation biomass is ignored in the present study. The net carbon balance of an ecosystem can be calculated from the net ecosystem production (NEP), which is calculated through the difference in the gross primary production (GPP) and the autotrophic ecosystem respiration (Xie et al. 2008). The carbon absorbed by different kinds of vegetation is reflected by the NEP, and the carbon sink is calculated as follows:

$$\mathrm{CA} = \mathrm{Area_f} \times \mathrm{NEP_f} + \mathrm{Area_g} \times \mathrm{NEP_g} \tag{2}$$

where CA represents the amount of carbon absorbed by different types of land use (t). $\mathrm{Area_f}$ and $\mathrm{Area_g}$ are the area of forests and grasslands (hm^2), respectively. $\mathrm{NEP_f}$ and $\mathrm{NEP_g}$ refer to the NEP (t/hm^2) of forests and grasslands, respectively. The NEP of forests and grasslands are computed following the approach given by Xie et al. (2008), and the $\mathrm{NEP_f}$ and $\mathrm{NEP_g}$ are estimated to be 3.809529 t/hm^2 and 0.949483 t/hm^2, respectively.

We defined C footprint as the area of productive land—vegetation—needed to absorb C emissions, i.e., the ecological footprint of C emissions (Zhao et al. 2011; Mikulčić et al. 2016). The C ecological capacity and C ecological deficit are calculated by the following equations:

$$\mathrm{CFT} = \mathrm{CE} \times \left(\frac{\mathrm{Per_f}}{\mathrm{NEP_f}} + \frac{\mathrm{Per_g}}{\mathrm{NEP_g}} \right) \tag{3}$$

$$\mathrm{CEC} = \mathrm{CA} \times \left(\frac{\mathrm{Per_f}}{\mathrm{NEP_f}} + \frac{\mathrm{Per_g}}{\mathrm{NEP_g}} \right) \tag{4}$$

$$\mathrm{CED} = \mathrm{CFT} - \mathrm{CEC} \tag{5}$$

where CFT refers to the C footprint (hm^2). $\mathrm{Per_f}$ and $\mathrm{Per_g}$ are the proportions of the total carbon absorption by forests and grasslands, respectively. $\mathrm{NEP_f}$ is NEP (t/hm^2) of

forests. NEP_g is NEP (t/hm^2) of grasslands. Per_f and Per_g, respectively, are 82.72% and 17.28%. CEC refers to the C ecological capacity (hm^2), and CED means the C ecological deficit (hm^2).

Spatio-temporal analysis of carbon footprint

The center of gravity method is used to analyze the spatio-temporal evolution of C footprint. Assuming that all cities in Zhejiang Province are homogeneous, the C footprint of each city is concentrated in the center of each city. The center of gravity is calculated as

$$\text{Long} = \frac{\sum_{i=1}^{n=11} \text{CFT}_i \times \text{long}_i}{\sum_{i=1}^{n=11} \text{CFT}_i} \tag{6}$$

$$\text{Lat} = \frac{\sum_{i=1}^{n=11} \text{CFT}_i \times \text{lat}_i}{\sum_{i=1}^{n=11} \text{CFT}_i} \tag{7}$$

where Long and Lat refer to the longitude and latitude of C footprint gravity centers of Zhejiang Province, respectively. CFT refers to the C footprint (hm^2) of the city i. long_i and lat_i are the longitude and latitude of the city i center, respectively.

Results and discussion

Evolution of carbon emissions

Total C emissions in Zhejiang Province and C emissions in four selected cities, Ningbo, Hangzhou, Shaoxing and Zhoushan, during 2005–2015 are shown in Fig. 2a. The C emissions for the eleven prefecture-level cities of Zhejiang Province are given in Table S1. Results show that total Zhejiang emissions increased from 73.16 million tons in 2005 to 113.99 million tons in 2011, of + 55.8%. The corresponding rate of emissions is 6.8 million tons per year. Then, emissions gradually decreased by − 5.8% from 2011 to 2015. These findings are explained by the implementation of national-level policies, named '5-year plans' by the Chinese government. Indeed, during the eleventh plan from 2005 to 2010, the economy and industry had developed rapidly in Zhejiang Province, resulting in large increases in C emissions from higher energy consumption. Then, during the twelfth plan from 2011 to 2015, energy conservation, emission reduction and industrial upgrading explain the global decrease in C emissions. The trend of C emissions during the eleventh and twelfth plans in Zhejiang Province coincides well with previous studies (Deng et al. 2015; Song et al. 2015). The emission rates in various cities are discussed below.

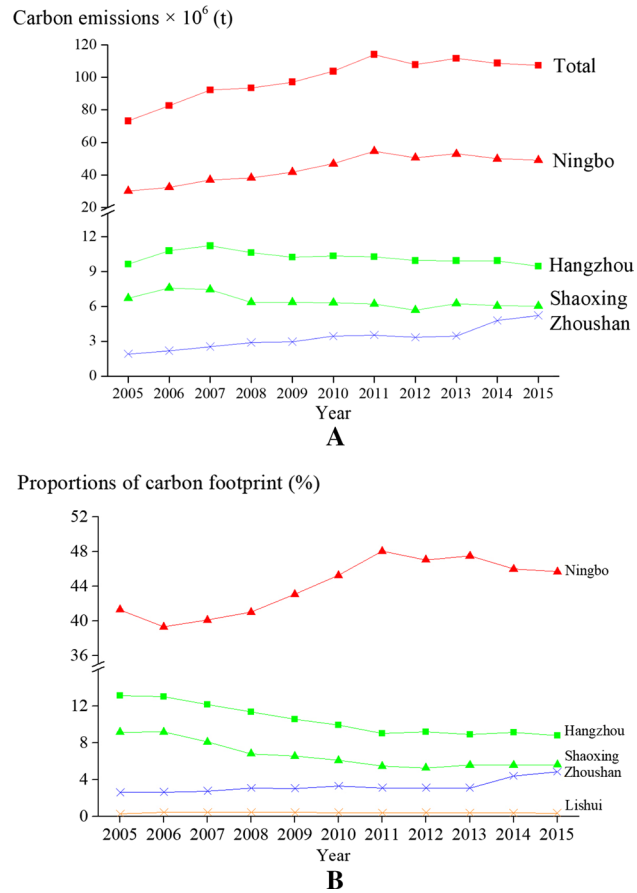

Fig. 2 **a** Carbon emissions in Zhejiang Province during 2005–2015. Two patterns can be observed: (1) Total and Ningbo carbon emissions increase from 2005 to 2011 and then decline slightly from 2011 to 2015. Carbon emissions in Hangzhou and Shaoxing also increase and then decline since 2007. (2) Zhoushan shows low but steadily increasing emissions. These findings show that the temporal evolution of C emissions in cities on a same province is highly heterogeneous. **b** Proportions of carbon footprint of five cities in Zhejiang Province during 2005–2015. We observe that Ningbo had the largest proportion of carbon footprint, and Lishui had the lowest proportion. Both Hangzhou and Shaoxing footprint percentages show a decline, while Zhoushan footprint percentage shows an increase from 2005 to 2015

Figure 2a shows that the amount and the evolution of C emissions are different in different cities. For instance, Ningbo always shows the largest amounts of C emissions, of an average of 44.02 million tons annually during 2005–2015. C emissions in Ningbo increased from 30.21 in 2005 to 49.05 million tons in 2015. Ningbo and total province emissions show a similar trend, increasing from 2005 to 2011 and then slightly decreasing from 2011 to 2015. Hangzhou and Shaoxing were the second and third emitters with mean 10.21 and 8.82 million tons annually. The smallest C emissions were in Lishui, amounting to only 0.21 million tons in 2005 and 0.39 million tons in 2015 (Table S1). This is explained by the economical lagging of Lishui compared to

other cities. Similarly, C emissions in Zhoushan were low, which is explained by the fact that Zhoushan is an urbanized archipelago where fishing is the main activity and other industrial sectors are not developed. Nonetheless, Zhoushan shows a steady increase in C emissions, accelerating from 2013. These spatial characteristics of C emissions in different cities are consistent with the study of Liu et al. (2018). Only two cities show an overall decline from 2005 to 2015: In Hangzhou, C emissions declined from 9.63 to 9.46 million tons and in Shaoxing from 6.70 to 6.04 million tons. In Hangzhou, this is explained by the upgrading and optimization of the industrial sector.

Overall, our findings show that the amounts and evolution of C emissions are different in different cities. Two patterns can be distinguished: (1) The largest cities have high emissions, but emissions are now declining due to the optimization of the industry and (2) most of the smallest cities show a steady increase in emissions due to their ongoing development. Also, some cities have very specific economic activities, such as fishing in Zhoushan, which makes this city a very low C emitter. Therefore, policies aiming at reducing CO_2 emissions should take into account not only the size, but also the temporal variation of C emissions and the economic characteristics of each city.

Evolution of carbon footprint

The C footprint is the land area in hm^2 needed to absorb C emissions. The C footprint for Zhejiang Province and prefecture-level cities was calculated for 2005–2015 using the C footprint, as shown in Eq. 3. Results show that the C footprint of Zhejiang Province increased by 55.8%, from 29,201,904 hm^2 in 2005 to 45,496,817 hm^2 in 2011. This increase is mainly caused by energy consumption. Then, during 2011–2015, the C footprint declined by 5.8%, from 45,496,817 hm^2 in 2011 to 42,870,120 hm^2 in 2015. This decrease is explained by upgrading and optimization of the industrial sector.

For cities, Ningbo has the largest C footprint, whereas Lishui has the lowest (Fig. 2b). In Ningbo, the C footprint increased from 12,056,565 hm^2 in 2005 to 21,851,002 hm^2 in 2011, and in Lishui City, the amount increased by 115.5% from 85,323 hm^2 in 2005 to 183,859 hm^2 in 2011. During 2011–2015, except cities of Wenzhou, Huzhou, Quzhou and Zhoushan, all other cities show declining C footprint, reaching a highest reduction of 28.6% in Taizhou. Again, this decrease is the result of the Twelfth Five-Year Plan from 2011 to 2015, which promoted the industrial transformation and upgrading and accelerated the application of low-carbon technologies. For instance, in the daily life, electric motorbikes, electric scooters and electric vehicles are becoming more popular than ever (Du et al. 2019).

We also calculated the proportions of C footprint in each city (Fig. 2b, Table S2). Results show highly different values, with Ningbo being by far the largest contributor with 45.67% in 2015, followed by Hangzhou (8.81%) and Jiaxing (8.36%). Lishui shows the lowest proportion of C footprint of 0.36% in 2015. From 2005 to 2015, the proportion of C footprint decreased from 13.17% in 2005 to 8.81% in Hangzhou and from 9.15% to 5.62% in Shaoxing. This finding is in line with less C emissions from industrial optimization. On the other hand, Zhoushan shows low but increasing proportion of C footprint, which is in agreement with the more recent development of this city.

Evolution of carbon ecological deficit

To assess the ecological pressure caused by energy consumption, we mapped the C footprint and the C ecological capacities and deficits of cities from 2005 to 2015 (Fig. 3). The C ecological deficit, expressed in hm^2, is the C footprint minus the C ecological capacity (Eq. 5). The C ecological capacity is the surface of land able to absorb C emissions. A positive deficit means that the all emissions cannot be absorbed, thus favoring global warming. A negative deficit means that the land is able to absorb more C than emissions, thus offsetting global warming.

Results at the province level show that the C ecological capacity decreased slightly from 8,638,836 hm^2 to 8,621,828 hm^2, whereas the C ecological deficit increased from 20,563,068 hm^2 to 34,248,292 hm^2 from 2005 to 2015. These findings show that the productive land area is not sufficient to compensate for C emissions. Here, the compensation rate has low values, of 29.6% in 2005 and 20.1% in 2015, which means that the C cycle is still under excessive pressure. This trend is explained by economic and manpower changes. Indeed, since the mid-1990s, the industrialization and urbanization have grown in Zhejiang Province, with population rising from 22.8 million in 1950 to 56.6 million in 2017. However, the farmland area of the province has declined by 20.49%, of 5900 km^2, from 1990 to 2010 (Wu et al. 2015; Zhu et al. 2019). In addition, a large number of rural workers engaged in agricultural activities are now working in manufacturing and service sectors, leading to the reduction in agricultural manpower. From 1997 to 2007, the agricultural manpower had reduced from 51 to 29%. Therefore, the province relies on high-carbon agricultural inputs to maintain food production needs (Dong et al. 2013). Overall, our findings show that the C ecological deficit is still high at the province level.

At the city level, in 2015, the C ecological capacity varies widely, from 2,062,472 hm^2 in Lishui to 1,555,891 hm^2 in Hangzhou and 5440 hm^2 in Jiaxing. As a consequence, the C ecological deficit is highly different from one city to another city, as shown in red bars in Fig. 3. Ten cities show positive

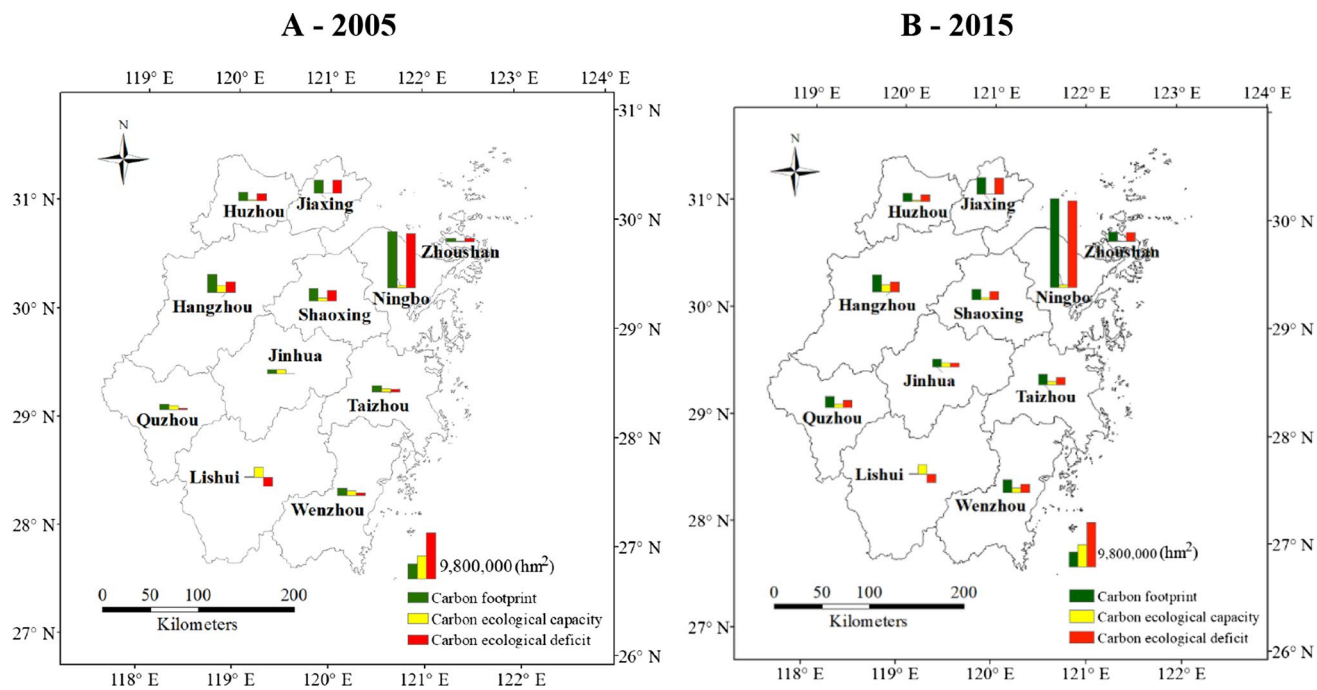

Fig. 3 Carbon footprint (green), carbon ecological capacity (yellow) and carbon ecological deficit (red) in eleven prefecture-level cities in Zhejiang Province in 2005 (**a**) and 2015 (**b**). In most cities, the carbon footprint in 2015 is higher than that in 2005, and the carbon emission load exceeds the carbon ecological capacity. Note the high variability of all data at the city level. Note also that only Lishui has an ecological surplus

ecological deficits, whereas Lishui has a negative deficit and thus an ecological surplus of 1,906,596 hm^2. Ningbo has by far the largest C ecological deficit of 19,010,685 hm^2 in 2015 and 11,496,867 hm^2 in 2005 due to high C emissions. This deficit is much lower in Jiaxing, Hangzhou, Zhoushan, Shaoxing, Wenzhou, Quzhou, Taizhou, Huzhou and Jinhua. Overall, our findings show again a high heterogeneity at city levels, some cities being much less environmentally friendly than others. Therefore, future environmental policies should take into account the ecological deficit at the city level.

Spatial evolution of the gravity center of the carbon footprint

To study the spatial evolution of the C footprint, the central coordinates including longitude and latitude of each prefecture-level city were acquired. The province center of yearly C footprint during 2005–2015 was calculated using the method of the center of gravity (Eqs. 6 and 7). Then, the yearly centers of gravity were connected with lines to build the evolution curve (Fig. 4). Results show that the C footprint gravity center evolves in the Shaoxing City area, in the northern part of the province. The center moves southeast from 2005 to 2015. Three stages can be distinguished.

First, during 2005–2006, the C footprint center of gravity shifted westward by 0.039° and northward by 0.016°. This is explained by an increase in proportions of C footprint in Huzhou, of 0.42%, and Jiaxing, of 0.95%, located north. However, a decrease in proportions of C footprint is observed in Ningbo City, of −1.98%, and Taizhou City, of −0.61%, located east; and Wenzhou City, of −0.60%, located south (Table S2). These changes induce an overall shift to the northwest. The increase in proportions of C footprint is consistent with the increase in C emissions in Huzhou, of 20.46%, and Jiaxing, of 23.82%, during 2005–2006.

Second, during 2006–2011, the C footprint moved east by 0.161° and south by 0.104°. The proportions of C footprint decreased in Hangzhou, of −4.04%, Jiaxing, of −2.69%, Huzhou, of −2.73%, and Shaoxing, of −3.73%, located north, while the proportions of C footprint increased in Ningbo (8.72%), Wenzhou (0.81%) and Taizhou (3.23%), located east. As a result, the C footprint center of gravity shifted southeast, as shown by the arrow in Fig. 4. The decrease in proportions of C footprint in northern cities during this period coincides with the decrease in C emissions, as shown in Fig. 2a. The C emissions decreased in Hangzhou, of −4.68%, Huzhou, of −17.72%, and Shaoxing, of −18.05%, while it increased in Ningbo, of 68.64%, Wenzhou, of 60.70%, and Taizhou, of 150.25%, during 2006–2011 due to the fast industrialization and urbanization.

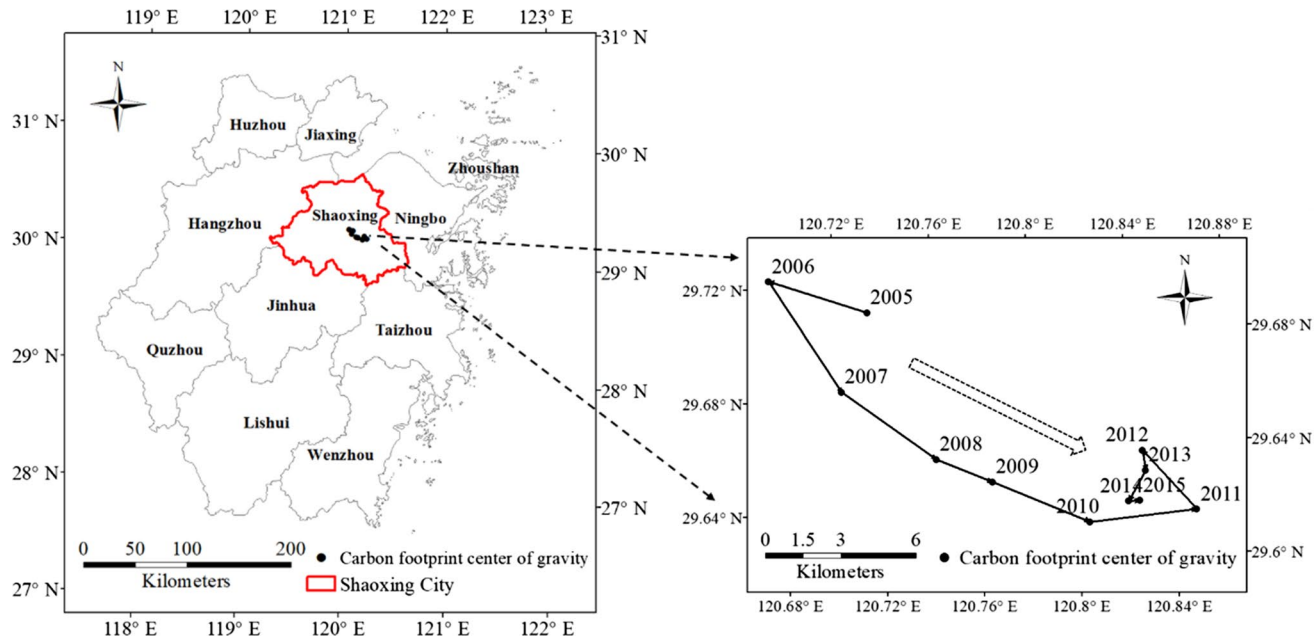

Fig. 4 Location of the carbon footprint center of gravity in Zhejiang Province and the evolution curve of the carbon footprint center of gravity for the period 2005–2015. We observe that the center of gravity was located in Shaoxing City, and shifted southeast during 2006–2011 as shown by the arrow

Third, during 2012–2015, the C footprint moved south by 0.018°. The proportions of C footprint increased in Wenzhou City by 1.26% and in Quzhou by 0.79%, but decreased in Ningbo by 1.38% and in Jiaxing by 1.42%. The decrease in proportions of C footprint during this period in Ningbo and Jiaxing also coincides with the decrease in C emissions. The C emissions decreased in Ningbo, of − 3.30%, and Jiaxing, of − 14.78%, due to the low carbon development of the Twelfth Five-Year Plan.

Overall, our findings show the different evolution of C emissions in different cities. The C footprint in Zhejiang Province increased from 2005 to 2011 and then declined during 2011–2015. High spatio-temporal heterogeneity of carbon footprints is observed. Ningbo City has the largest C footprint contribution, whereas Lishui the lowest. High C ecological deficit at the province level and high heterogeneity of C ecological deficit at city levels are found. The center of gravity of the C footprint evolves in Shaoxing City and shows an overall southeast shift from 2005 to 2015.

Conclusion

We have studied C emissions, footprint and ecological deficit for cities in Zhejiang Province. Emissions increased during the Eleventh Five-Year Plan period (2005–2010) as a result of industrial and economic development. Then, emissions decreased during the Twelfth Five-Year Plan period (2011–2015), due to industrial optimization and low-C incentives. The C footprint of the province increased by 46.8% during 2005–2015, with Ningbo being the largest contributor. As a consequence, there was not enough productive land to compensate for C emissions, resulting in a high C ecological deficit at the province level. At the city level, ten cities show ecological deficits, whereas one city shows an ecological surplus in 2015. This is explained by difference in energy consumption and productive land area. The center of gravity of the C footprint shows an overall southeast shift in Shaoxing, which is explained by the changes in the contributions of the C footprint at the city level.

In conclusion, our findings show that the values of C footprint and C ecological deficit are highly heterogeneous at city levels and change with time. As a consequence, future policies aiming to offset climate change should take into account spatial and temporal heterogeneities at the local level.

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Supplementary Material

High spatio-temporal heterogeneity of carbon footprints in the Zhejiang Province, China, from 2005 to 2015: implications for climate change policies

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Table S1. Carbon emissions in million tons in each city of the Zhejiang Province during 2005-2015

Year	Hangzhou	Ningbo	Wenzhou	Jiaxing	Huzhou	Shaoxing	Jinhua	Quzhou	Zhoushan	Taizhou	Lishui	Total
2005	9.63	30.21	4.04	7.13	4.63	6.70	2.23	3.12	1.90	3.35	0.21	73.16
2006	10.77	32.46	4.06	8.83	5.58	7.59	3.47	3.97	2.18	3.28	0.38	82.59
2007	11.20	36.95	4.17	8.46	5.69	7.45	5.44	4.30	2.53	5.58	0.41	92.19
2008	10.62	38.30	4.25	8.07	5.27	6.36	5.42	4.38	2.88	7.45	0.42	93.42
2009	10.23	41.85	4.89	8.12	5.17	6.35	4.76	5.06	2.95	7.35	0.42	97.14
2010	10.34	46.96	5.78	8.09	4.64	6.31	4.93	5.23	3.44	7.64	0.43	103.77
2011	10.27	54.75	6.53	9.13	4.59	6.22	5.11	5.19	3.53	8.21	0.46	113.99
2012	9.94	50.72	5.84	10.54	4.12	5.68	4.81	5.39	3.33	6.99	0.46	107.80
2013	9.92	53.04	5.93	10.26	4.18	6.23	4.94	6.05	3.45	7.21	0.43	111.65
2014	9.92	50.00	6.78	9.40	4.21	6.05	4.58	6.35	4.78	6.23	0.42	108.71
2015	9.46	49.05	7.16	8.98	4.65	6.04	4.37	6.22	5.23	5.86	0.39	107.41

Table S2. Proportions of carbon footprint in the Zhejiang Province during 2005-2015, in %

Cities	Hangzhou	Ningbo	Wenzhou	Jiaxing	Huzhou	Shaoxing	Jinhua	Quzhou	Zhoushan	Taizhou	Lishui
2005	13.17	41.29	5.52	9.75	6.34	9.15	3.05	4.26	2.60	4.58	0.29
2006	13.05	39.31	4.92	10.70	6.76	9.19	4.20	4.80	2.64	3.97	0.46
2007	12.15	40.08	4.52	9.18	6.17	8.08	5.90	4.67	2.75	6.05	0.45
2008	11.36	41.00	4.55	8.64	5.64	6.81	5.80	4.69	3.08	7.98	0.45
2009	10.54	43.08	5.03	8.35	5.32	6.54	4.90	5.21	3.04	7.56	0.43
2010	9.96	45.25	5.57	7.80	4.47	6.08	4.75	5.04	3.31	7.36	0.41
2011	9.01	48.03	5.73	8.01	4.03	5.46	4.49	4.55	3.09	7.20	0.40
2012	9.22	47.05	5.41	9.78	3.82	5.27	4.46	5.00	3.09	6.48	0.42
2013	8.89	47.50	5.31	9.19	3.75	5.58	4.42	5.42	3.09	6.46	0.39
2014	9.12	45.99	6.24	8.64	3.88	5.57	4.21	5.84	4.40	5.73	0.38
2015	8.81	45.67	6.67	8.36	4.33	5.62	4.07	5.79	4.86	5.46	0.36