Research on urban density model and resilient development model under the guidance of carbon emission

Shifang Shen1*, Yiting Yu2
1 School of urban construction and safety engineering, Shanghai Institute of Technology, Shanghai, 201418, China
2 School of urban construction and safety engineering, Shanghai Institute of Technology, Shanghai, 201418, China
*Corresponding author’s e-mail: 18326138468@163.com

Abstract. In this study, we used time series data from 2001 to 2018 to quantify the relationship between urban density and carbon emissions in Shanghai. The regression equation is used to analyze the relationship between urban carbon emissions and urban density in the past ten years. According to national policies and the calculation of peak carbon emissions, the urban density under the peak carbon emissions is derived as the appropriate urban density. This paper puts forward the concept of urban density index, calculates the density index of Shanghai and analyzes it.

1. Introduction
Many scholars at home and abroad have studied the influencing factors of carbon emissions. Liddle (2004)1 found that there is a significant negative correlation between population density and per capita road energy use in the United States. Brown et al (2009)2 proposed that the density of residential buildings is directly related to carbon emission. The carbon emission of suburban households with 4 households per hectare is is 25% higher than that of urban households with 20 households per hectare. Peng mi (2010)3 concluded that the energy consumption of road system in China accounted for more than 50% of the energy consumption of the whole transportation sector. It can be seen that transportation has a greater impact on carbon emissions. Some scholars believe that urban structure and land use have certain impact on urban carbon emissions. For example, Edward L Glaeser (2010) empirically analyzed that the greater the intensity of land development, the lower the per capita carbon emissions of residents' transportation. Lv Bin (2013)5 believes that urban spatial form plays an important role in the realization of urban low-carbon development.

However, the relationship between urban density and urban energy consumption is still controversial. Fan Jin (2011) believes that urban density will affect urban traffic energy consumption. Low density development will also lead to the increase of commuting distance, which will also increase traffic energy consumption. Urban density will affect urban household energy consumption. In low-density cities, people have larger housing area, higher requirements for heating, cooling and lighting, and more dependence on energy equipment, so the corresponding household energy consumption such as electric power consumption and gas consumption will increase. However, Yasuyo makido (2012) 7 concluded that there is a significant correlation between the per capita carbon dioxide emissions of urban residents and the passenger transport sector and the spatial variables of urban morphology.
2. Data sources and research methods

2.1. Study area
This project selects Shanghai as the research area. Shanghai is the most populous city in China, which is located on both sides of the Yangtze River Delta in eastern China. The rapid economic development of Shanghai is at the cost of the rapid increase of its natural resources consumption. With the rapid development of urbanization, Shanghai's energy consumption and carbon emissions are increasing rapidly, and the population density is also growing. In contrast, Shanghai's central city has a high degree of population agglomeration, while the population density within the city area is low.

2.2. Data source and description
In the research of this project, the number of permanent residents, GDP, GDP per capita, total energy consumption, and building area of Shanghai since 1990 comes from the "Shanghai Statistical Yearbook" of various years. The area of urban construction land in Shanghai comes from the "China Urban Construction Statistical Yearbook, China Environmental Statistical Yearbook, and other micro-level data can be obtained with the help of big data systems, professional survey reports and urban spatial geographic information systems provided by professional software, and the data on the total length of urban roads and the area of urban roads comes from the "Statistical Yearbook of Urban Construction in China".

2.3. Research model

2.3.1. Application of basic and extended models. This part first determines the basic research model of the relationship between carbon performance and urban density. Draw lessons from the classic (1) environmental pressure equation, where I represents the impact of the environment, P represents the population size, A represents the average degree of wealth, and T represents the level of technology

$$ I = PAT $$

(1)

Due to its concise form, the IPAT model is often used to estimate the determinants of environmental pressure. However, the IPAT model only considers a limited number of variables-energy, wealth, and population. To overcome this shortcoming, Dietz and Rosa developed STIRPAT (Stochastic). In the formula, a is a constant term; b, c, d are parameters to be estimated; I is the impact of the environment; P is the population size; A is the average degree of wealth; T is the technical level; e is the random error. The IPAT model can be regarded as a special form of STIRPAT, where a = b = c = d = 1. In empirical research, the model usually adopts logarithmic form (2):

$$ \ln I = \ln a + b \ln P + c \ln A + d \ln T + \ln e $$

(2)

2.3.2. Model design and adjustment. Since the STIRPAT model allows more factors to be added, based on the methods used by previous scholars, we have carried out corresponding decomposition and improvement techniques for related variables.

Studies have shown that urban transport sector has become one of the sectors with the highest carbon emissions, and the change of traffic organization plays an important role in the development of urban spatial structure. And the coupling between urban spatial structure and traffic organization can help to reduce carbon emissions. Therefore, it is very important to analyze the impact of traffic organization on carbon emissions. According to the specific situation of the study area, we improved STIRPAT model, added traffic organization factors, and used urban road density to express traffic organization. The method used in this study is multiple linear regression analysis and coefficient correlation test. In the selection of independent variables, in order to avoid multicollinearity among independent variables, variables with correlation no more than 0.7 are selected, and these independent variables and dependent variables should have strong correlation, so as to be able to explain the dependent variables effectively. Therefore, the final selected dependent variable I is the carbon
performance, the independent variable P is the population size, expressed by population density data, the average wealth of A is calculated by per capita GDP, and the technology level T is expressed by the ratio K coefficient of carbon dioxide and energy consumption. Traffic organization factors are expressed by urban road density. Urban road density (RD) refers to the total length of the regional road network divided by the area of urban construction land. The correlation analysis among various factors is shown in the following table1.

| Table 1. Correlation analysis of independent variable and dependent variable in regression. |
|---------------------------------|--------------------------------|
|                                 | Variable |
|                                 | CO2/L    | P/L    | Per Capita GDP | RD |
| CO2/L                           | Pearson Correlation | 1      | .626**          | .849** | .910** |
| P/L                             | Pearson Correlation | .626** | 1               | .183 | .693* |
| Per Capita GDP                  | Pearson Correlation | .849** | .183            | 1 | -.152 |
| RD                              | Pearson Correlation | .910** | .693*           | -.152 | 1 |

The improved STIRPAT model is as follows:

$$\ln \frac{CO2}{L} = \beta_1 \ln \frac{P}{L} + \beta_2 \ln \frac{GDP}{P} + \beta_3 \ln RD + \epsilon$$

(3)

Among them, CO2 represents CO2 emission, CO2 / L represents carbon performance, P / L represents population density, GDP / P represents per capita GDP, RD represents road network density, and e is random error.

2.4. Calculating the peak of carbon emission in Shanghai

According to Kaya formula, CO2 emission can be divided into three main driving factors: GDP, primary energy consumption per unit GDP (GDP energy consumption) and CO2 emission per unit energy (energy carbon intensity), the product of the last two items is the carbon emission intensity per unit of GDP, namely:

Total CO2 emissions = GDP × (CO2 / GDP)

= GDP × (energy consumption/GDP) × (CO2 / energy consumption)

= Population × (GDP / population) × (energy consumption/GDP) × (CO2 / energy consumption)

Thus, the total CO2 emissions can be decomposed into the product of population, GDP per capita, GDP energy intensity and energy carbon intensity. These four parameters respectively represent the social, economic, and energy status of a region related to low-carbon development.

$$CO_2 \text{ emissions} = P \times \frac{GDP}{P} \times \frac{E}{GDP} \times \frac{CO_2}{E}$$

(4)

3. Results and discussion

3.1. Regression equation analysis results

The data of carbon performance, population density, per capita GDP and road network density from 2001 to 2018 are put into multiple regression equation (3), and the results are shown in Table2.

| Table 2. Results of regression analysis. |
|---------------------------------|--------------------------------|
|                                 | Model Summaryb |
|                                 | R       | R²      | Adjusted R-squared | Standard error of estimate | Durbin-Watson |
|                                 | 1       | .950a   | .902              | .860                  | .011327677624886 | 2.254   |
After adjustment, the R-square is 0.86, the fitting degree of the regression equation is good, the significance of the independent variables is less than 0.1, and there is a strong correlation with the dependent variables. The collinearity between the independent variables is less than 10, which meets the conditions. Therefore, the regression equation between carbon performance and population density, per capita GDP, and road network density in Shanghai is obtained (5)

$$\ln \frac{CO_2}{L} = 1.544 + 0.54\ln P/L + 0.045\ln GDP\;L + 0.495\ln RD$$

(5)

According to the results of regression analysis, some factors that may be related to carbon performance are selected and analyzed. The results are shown in Table 3.

Table 3. Analysis of correlation factors of CO2/L.

| Correlation analysis of CO2 / L | P/L | 0.638** | A/L | 0.839** |
|--------------------------------|-----|---------|-----|---------|
| Total length of urban road | -0.98 | GDP | 0.734** |
| Road network density | 0.905** | gdp energy intensity | -0.852** |
| GDP/L | 0.782** | CO2/GDP | -0.843** |
| Per Capita GDP | 0.752** | labour productivity | 0.553** |
| Energy consumption | 0.891** | Total consumption expenditure of urban residents | 0.679** |
| Resident population | 0.839** | Total construction area | 0.732** |

According to Pearson correlation analysis, Shanghai's carbon performance (CO2/L) has a strong correlation with road network density, with the total energy consumption, the number of permanent residents, building density, energy consumption per unit of GDP, and has a slightly strong correlation with population density, urban construction land area, per capita GDP, building area, total GDP and total consumption expenditure of urban residents.

3.2. Calculation of carbon emission peak value by scenario analysis method

In its "Nationally Determined Contributions", China proposed that carbon dioxide emissions will reach a peak around 2030 and strive to achieve it as soon as possible. In 2030, carbon dioxide emissions per unit of GDP will be reduced by 60%-65% compared to 2005. Therefore, the scenario analysis method is used to predict Shanghai's carbon emissions in 2030. The scenario analysis process is shown in Table 4.

Table 4. Scenario analysis of carbon emission peak.

| CO2 emissions (2018=1) | Inertia scenario | Planning scenario | Ideal scenario |
|------------------------|------------------|-------------------|---------------|
| 2020                   | 1.03             | 1.091             | 1.057         |
|                        |                  | 1.115             |               |
| 2025                   | 1.12             | 1.354             | 1.215         |
|                        |                  | 1.464             |               |
| 2030                   | 1.22             | 1.779             | 1.396         |
|                        |                  | 2.033             |               |
3.2.1. **Inertia scenario.** The annual average population growth rate is 1.04%, the average annual growth rate of GDP per capita is 7.54%, and the average reduction rate of energy intensity per unit GDP is 6.42%. The CO2 emissions in 2020, 2025 and 2030 are estimated. The peak of CO2 emission in 2030 is 1.22 times that of 2018, about 372.1 million tons.

3.2.2. **Planning scenario.** In the "national independent contribution", China proposed that the carbon dioxide emission would reach the peak value around 2030 and strive to achieve it as soon as possible. In 2030, the carbon dioxide emission per unit of GDP would be reduced by 60% - 65% compared with that in 2005. According to the planned average population growth rate of 0.18%, and the per capita GDP growth rate of 6.0%, and based on the reduction of GDP carbon dioxide emissions by 60% - 65% in 2030 compared with 2005, the carbon dioxide emission in 2030 is estimated to be 1.779-2.033 times of that in 2018, which is about 542.620 million tons.

3.2.3. **Ideal scenario.** If the energy intensity per unit of GDP is reduced by 3.0% per year on the basis of 2018, and the per capita GDP growth rate is 6.0%, assuming that the population does not grow under the ideal scenario, the average annual growth rate of CO2 emissions will be 2.8%, and the carbon emissions in 2030 will be about 425 million Ton.

3.3. **Analysis of urban density**

3.3.1. **Analysis on the change law and reason of urban population density.** According to the statistical data, the number of permanent residents in Shanghai increased at a constant rate from 2001 to 2013, and the increase was less after 2013. However, the area of construction land in Shanghai increased greatly from 2007 to 2009, and increased a lot from 2013 to 2014. Therefore, the population density decreased in 2007-2009 and 2013-2014.

3.3.2. **Calculate the appropriate city density Dx under the peak carbon emission.** Substitute peak carbon emissions into the regression equation (5). It is assumed that from 2019 to 2030, the per capita GDP is calculated according to the growth rate under each scenario mode, the road network density remains unchanged, and the construction land area remains unchanged, which is still 3088 square kilometers. The urban density under each scenario mode is inverted, that is, the appropriate urban density DX under the peak carbon emission. The calculation process is shown in Table 5.

|  | 2030 | Inertia scenario | Planning scenarios | Ideal scenario |
|---|---|---|---|---|
| CO2 (10000 tons) | 37210 | 54260 | 62020 | 42578 |
| L (square kilometre) | 3088 | 3088 | 3088 | 3088 |
| Per capita GDP (yuan) | 322935 | 271584 | 271584 | 271584 |
| RD (Km / km2) | 1.692 | 1.692 | 1.692 | 1.692 |
|                | 12.05   | 17.571  | 20.084  | 13.788  |
|----------------|---------|---------|---------|---------|
| ln(CO2/L)      | 2.489   | 2.866   | 3       | 2.624   |
| lnPer capita GDP| 12.685  | 12.512  | 12.512  | 12.512  |
| lnRD           | 0.526   | 0.526   | 0.526   | 0.526   |
| 0.54 ln(P/L)   | 0.11389355 | 0.498896396 | 0.632566003 | 0.256446777 |
| ln(P/L)        | 0.211   | 0.924   | 1.171   | 0.475   |
| P/L(10000 people / km2) | 1.235 | 2.519 | 3.227 | 1.608 |

(1) Under the inertial scenario: the carbon dioxide emission in 2030 will be 646.4 million tons. Assuming that the construction land area will not grow any more since 2017 and maintain 3088 square kilometers, the per capita GDP is predicted to be 322935 yuan, and the road network density is assumed to remain at 1.6917 in 2017, and the population density in 2030 is calculated to be 123500 person / km².

(2) Under the planning scenario: the carbon dioxide emission in 2030 will be 542.6-620.2 million tons. Assuming that the construction land area will not increase since 2017 and maintain 3088 square kilometers, the per capita GDP is predicted to be 304005 yuan, and the road network density is assumed to remain at 1.6917 in 2017, the population density in 2030 is calculated to be 2.519-3.227 million people / km².

(3) Under the ideal scenario: carbon emissions in 2030 are about 425 million tons, and the population density in 2030 is calculated to be 16,088 million people per square kilometer.

4. Conclusions
In this study, we speculate on the appropriate urban density range under the peak of carbon emission, and understand the development trend of urban density in Shanghai in the future under the background of different policy environments. In the study, we found that the factors influencing carbon emissions in the city are divided into traffic indicators, social and economic indicators, urban morphology, population indicators, building indicators, and then the indicators of all levels. More factors affecting carbon emissions can be found, such as gasoline consumption, green coverage, population structure, land mix, etc. At the beginning of putting forward the concept of urban density index, the purpose of this study is to compare and analyze the density index of several cities in the Yangtze River Delta. After that, there are many parts waiting to be studied.

References
[1] Liddle, B. (2004). Demographic dynamics and per capita environmental impact: Using panel regressions and household decompositions to examine population and transport. Population and Environment, 26(1), 23–39.
[2] Brown, M. A., Southworth, F., & Sarzynski, A. (2009). The geography of metropolitan carbon footprints. Policy and Society, 27(4), 285-304.
[3] Peng MI, Lv Bin, Zhang Chun & Huang Bin. (2010). Regional differences in energy carbon emissions and their influencing factors in China. Urban Development Research (07), 6-11 + 44.
[4] Glaeser, E. L., & Kahn, M. E. (2010). The Greenness of Cities: Carbon Dioxide Emissions and Urban Development. Journal of Urban Economics, 67(3), 404-418.
[5] Lv Bin & Sun ting. (2013). Study on the compactness of urban spatial form from the perspective of low carbon. Geographic research (06), 1057-1067.
[6] Fan Jin. (2011). An Empirical Study on the impact of urban density on urban energy consumption. China economic issues (06), 16-22.
[7] Makido, Y., Dhakal, S., & Yamagata, Y. (2012). Relationship between urban form and CO2 emissions: Evidence from fifty Japanese cities. urban climate, 2(2), 55-67.