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Original Paper

Research on the Characteristics of the Spatial and Temporal Distribution and Influencing Factors of Carbon Emissions: The Case of Chengdu

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Abstract

It is necessary to study the characteristics of the spatial and temporal characteristics and influencing factors of carbon emissions. Doing so holds great significance for optimizing urban spatial patterns and protecting the environment. Based on the ArcGIS and SPSS packages and Pearson correlation coefficient analysis, this study analyzed the carbon emission data, population data, gross domestic product (GDP) data and land use data of 19 districts and counties in Chengdu in 2000, 2005, 2010 and 2015. Based on the analysis, the characteristics of the temporal and spatial distribution and influencing factors of carbon emissions in Chengdu are discussed. We hope to provide a relevant basis for future urban construction and policy making in Chengdu. The research results show that the overall carbon emissions in Chengdu are increasing. Since 2010, the carbon emissions in the central city began to decrease, while the carbon emissions in other major carbon emission areas grew relatively slowly. Population, the economy and land use will affect carbon emissions in Chengdu.

Keywords

Carbon emissions, population, land use, economy, GIS, Pearson correlation coefficient

1. Introduction

With the acceleration of urbanization, great changes have taken place in people's production and lifestyle. The expansion of industry and people's unrestrained consumption of energy have brought a series of environmental problems, resulting in the occurrence of catastrophic weather. Carbon dioxide emissions caused by industrial production and automobile exhaust are increasing year by year, resulting in greenhouse effects, global warming and other environmental problems, seriously threatening the living environment of human beings. The environmental problems caused by carbon dioxide are currently one of the most severe tests faced by human beings and have attracted attention. To that end, countries around the world have actively made efforts.

China is one of the world's largest carbon emitters. According to statistics, China's carbon emissions in 1990 were approximately 2.26 billion tons, and they increased to approximately 7 billion tons in 2010. In other words, the amount increased by 4.74 billion tons in just 20 years. The reason is that China is in the stage of rapid development. In recent years, with the acceleration of urbanization and industrialization in China, the environment and resources have faced severe challenges. Seeking a sustainable development mode and building green low-carbon cities are the only way to achieve urban development.

Currently, the world emits approximately 51 billion tons of greenhouse gases into the atmosphere every year. To avoid a climate catastrophe, humans need to stop pumping greenhouse gases into the atmosphere and achieve net-zero emissions. Countries all over the world are working to achieve this goal. In September 2020, China clearly proposed the goal of reaching peak carbon emissions by 2030 and becoming carbon neutral by 2060, which has attracted great attention. Research shows that human activity is the main contributor to the increase in carbon dioxide emissions and that human activity mainly occurs in cities (Wu et al., 2020). Therefore, studying the characteristics and laws of carbon dioxide emissions holds great significance for guiding urban construction, optimizing the urban spatial structure and building low-carbon cities.

At present, the content of research on carbon emissions mainly focuses on the characteristics of the spatiotemporal distribution of carbon emissions (Wang et al., 2020) (Zhang, 2018) (Zhao et al., 2011) (Liu et al., 2015), the relationship between carbon emissions and land use (Wenfu et al., 2017) (Huang, Xia, & Yang 2013) (Zhang et al., 2014), social and economic development and the built environment (Shen et al., 2021) (Ye et al., 2015), and the calculation and influencing factors of carbon emissions (Wang, Feng, & Song, 2020) (Wang, Chen, & Fujiyama, 2015) (Kokotsaki, Menzies, & Wiggins, 2014) (Jiang, 2016). The commonly used methods of research on carbon emissions mainly include model estimation, field measurement and investigation, factor decomposition and remote sensing technology (Hou et al., 2019). The model estimation method mainly uses a model to calculate and estimate the carbon flow. Field measurement and research are mainly used for data acquisition and analysis through field observation and questionnaire distribution. The data obtained by this method are more accurate, but the workload is relatively large, and it is difficult to obtain large-scale data. Therefore, it is often

used in small-scale analysis and research. The factor decomposition method is a statistical analysis method that uses a statistical index system to analyze the degree of influence of each factor on the total change in the phenomenon. This method is often used to study the factors that influence carbon emissions. The logarithmic mean Divisia Index (LMDI) is one of the commonly used methods. Ferdinand et al. used the LMDI method to analyze the carbon emissions of the United States from 1990 to 2004 and found that the factors affecting carbon emissions mainly included the energy structure, per capita GDP, total population and carbon emissions per unit of energy (Vinuya, DiFurio, & Sandoval, 2010). Remote sensing technology is a method used to research carbon emissions that has emerged with the development of science and technology since the 21st century. Compared with traditional methods, it is real time and convenient, and the speed of updating and supervision is more convenient. It can be used to research and analyze the spatial distribution.

At present, carbon emission research data are mainly obtained in the following ways. First, relevant data are obtained through the literature. For example, population, economic and carbon emission data can be obtained through the statistical yearbook of each province. Second, corresponding data can be obtained by administering questionnaires. This method is often used for statistics on the travel mode, the travel frequency, transportation options and so on. The third method is obtaining data through field measurements, such as measuring carbon dioxide emissions at observation points through instruments. The fourth is obtaining relevant data through remote sensing technology and open source websites. Various data acquisition methods also provide a basis for research.

2. Study Area

In recent years, Chengdu has been an important city in Southwest China, and its construction and development have been widely studied. In January 2020, a policy for the construction of the Chengdu-Chongqing Twin Cities Economic Circle was implemented, in which ecological and environmental protection planning was regarded as an important link. At present, the compilation of ecological and environmental protection plan of the Chengdu-Chongqing Twin Cities Economic Circle is in progress. This paper uses the construction of the Chengdu-Chongqing Twin Cities Economic Circle and the combination of dual carbon targets and makes suitable schemes and mechanisms for joint atmospheric prevention and control in the Chengdu-Chongqing area. This will play an important supporting role in promoting the ecological coconstruction and environmental cogovernance of the Chengdu-Chongqing Twin Cities Economic Circle. Studying the carbon emission characteristics and laws of Chengdu, the core city of the Chengdu-Chongqing Twin Cities Economic Circle, plays an important role in the construction and optimization of the urban spatial structure and the protection of the ecological environment.

Based on this background, 19 districts and counties in Chengdu are selected for research. By analyzing the relationship between carbon emissions and population, the economy and land use, the

characteristics of the temporal and spatial distribution and rules of carbon emissions in Chengdu are studied, and the factors affecting carbon emissions in Chengdu are discussed.

Figure 1. Administrative Region of Chengdu

3. Data Sources

Considering the process of the temporal and spatial evolution of carbon emissions as well as the difficulty of data acquisition and collation, this study selected 2000, 2005, 2010 and 2015 data, meaning that the data had a five-year time interval. The data used in the research include carbon emission data, population data, gross domestic product (GDP) data, industrial GDP data, and land use classification and area data for Chengdu in the corresponding years of each district and county in the research area. China Emission Accounts and Datasets (CEAD) is the source of the carbon emission data for each region and county (Shan et al., 2017) (Shan et al., 2020). The population, GDP and industrial GDP data came from the Statistical Yearbook of Sichuan Province. The land use data for Chengdu were obtained from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences.

4. Research Methods

The main research method used in this paper is correlation analysis. Correlation analysis refers to the

analysis of two or more variable elements with a correlation to measure the degree of correlation between two variable factors. There are many correlation analysis methods, and the commonly used methods are covariance analysis, correlation coefficient analysis, unary regression analysis and multiple regression analysis. This study mainly discusses the relationship between population, the economy, land use and carbon emissions, so correlation coefficient analysis is adopted. The Pearson correlation coefficient is used in this paper. The Pearson correlation coefficient is often used to measure the correlation (linear correlation) between two variables X and Y, and it has a value between -1 and 1. The greater the absolute value is, the stronger the correlation.

In this paper, the ArcGIS package is used to analyze and process the carbon emission data of the research area, count the carbon emissions of each county, and calculate the carbon emission density of each county. On the basis of this analysis, the characteristics of the temporal and spatial distribution and rules of carbon emissions in Chengdu are discussed. At the same time, the paper uses the ArcGIS package to reclassify and sort the land use data and to obtain statistics on the area of each type of land. Finally, the paper uses the SPSS package to conduct correlation analysis on the relationship between carbon emissions and population, the economy and land use in Chengdu and to discuss the influence of each factor on carbon emissions in Chengdu.

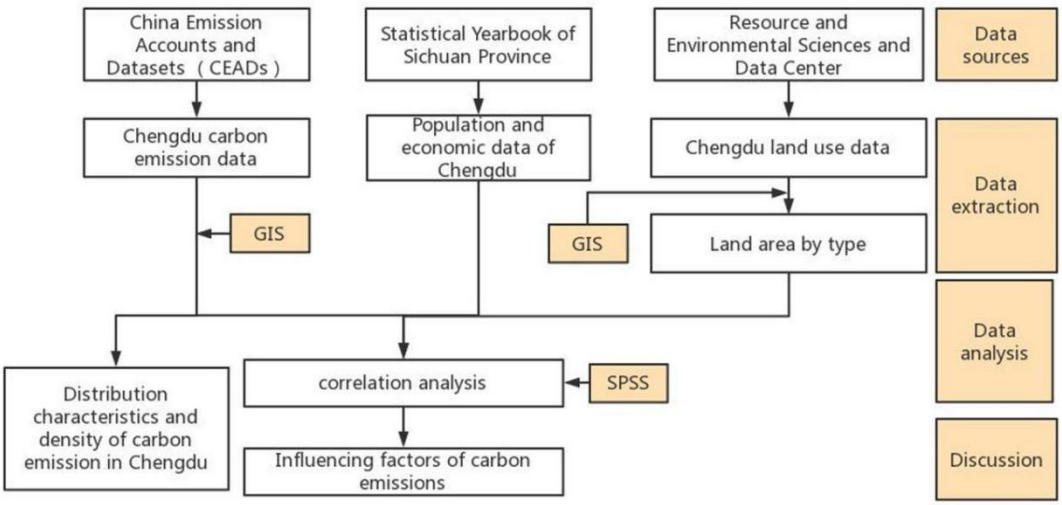

Figure 2. Research Approach

5.Results and Discussion

5.1 Characteristics of the Temporal and Spatial Distribution of Carbon Emissions in Chengdu

The research results indicate that the carbon emissions of each district and county in Chengdu showed a trend of rapid growth from 2000 to 2015. Among them, the carbon emissions of the Shuangliu, Xindu, Longquanyi and Pidu regions rank in the top four in Chengdu. Since 2010, these four regions have emitted more than 6 m tons of carbon per year. Notably, the carbon emissions of Wenjiang, Chenghua,

Wuhou, Jinniu, Qingyang, Jinjiang and other central areas of Chengdu all decreased in 2015 compared with 2010. Compared with 2010, the carbon emissions of Shuangliu, Pidu, Dujiangyan, Qionglai and other regions in 2015 also grew very slowly and even had a tendency to stop. The reason for this phenomenon is related to the energy-saving and emission reduction policies and industrial structure adjustment carried out in Chengdu in that year. In terms of carbon emission intensity, the Jinniu and Wuhou regions have the highest carbon emission intensity, followed by the Jinjiang, Qingyang and Chenghua regions. As shown by the research results, different from the distribution of total carbon emissions, the areas with high carbon emission density are mainly located in the central area of Chengdu.

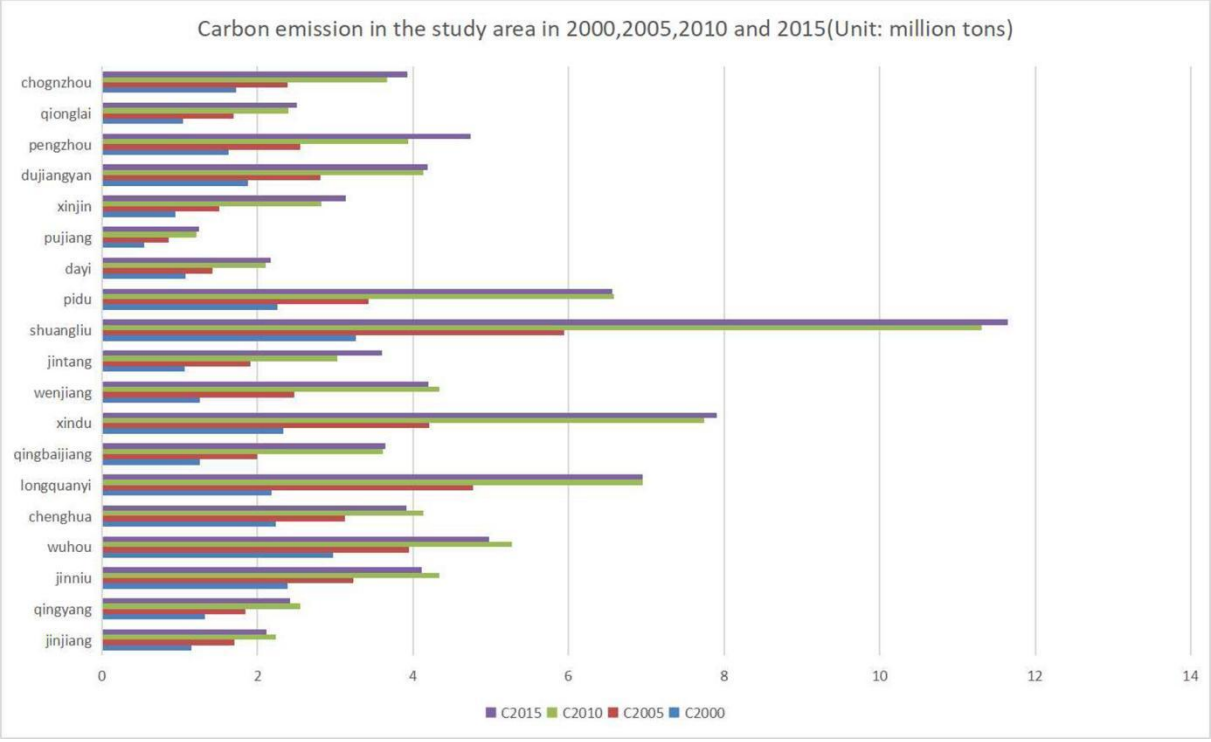

Figure 3. Carbon Emission in the Study Area in 2000, 2005, 2010 and 2015 (Unit: Million Tons)

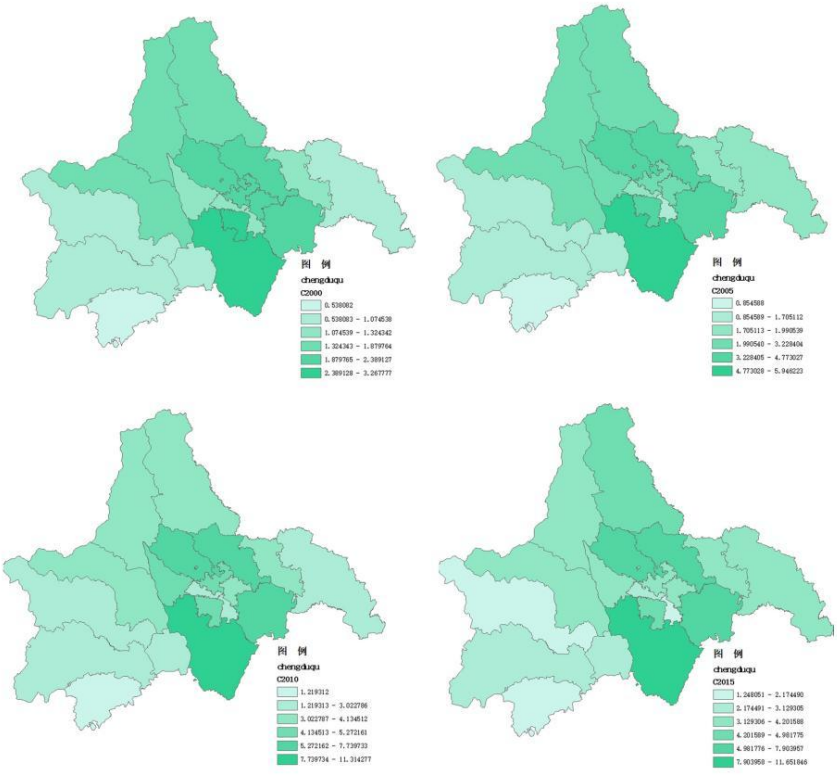

Figure 4. The Distribution of Carbon Emissions in the Study Area in 2000, 2005, 2010 and 2015

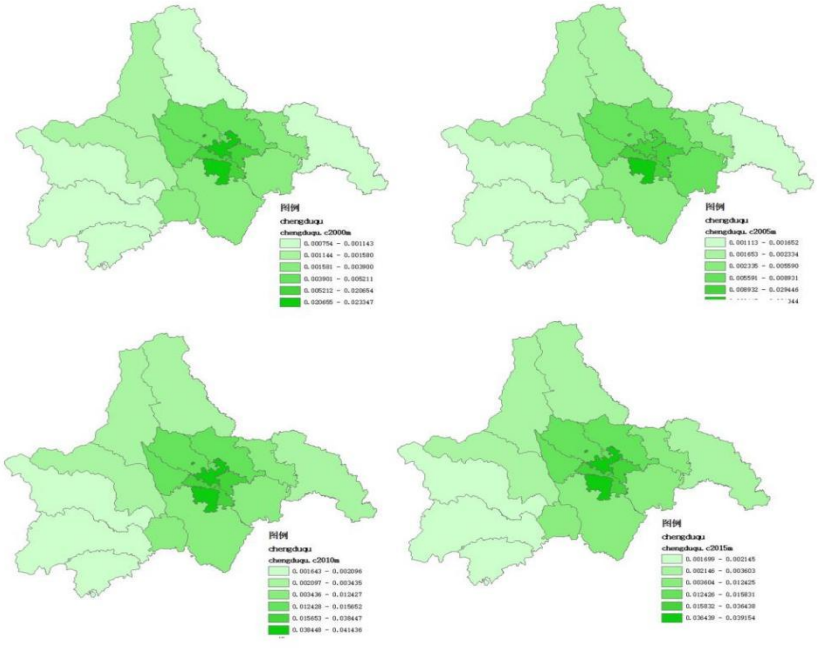

Figure 5. The Distribution of Carbon Emission Density in the Study Area in 2000, 2005, 2010 and 2015

5.2 Relationship between Carbon Emissions and Population

The correlation between carbon emissions and population, the economy and land use in each county was analyzed. The results indicate that there was a correlation between population and carbon emissions in each study region in 2000, 2005, 2010 and 2015. The results show that an increase in population will lead to an increase in carbon emissions. The reason is that population growth will lead to increased demands for transportation, housing, food and so on. These demands will require more industry, power and transport, which will consume more energy and increase carbon emissions. In addition, with the continuous development of cities and the improvement in the urbanization rate, the proportion of population urbanization is increasing. Changes in the production, living and consumption habits of people will also affect energy consumption and carbon emissions.

5.3 Relationship between Carbon Emissions and Land Use

A geographic information system divides urban land into cultivated land, forestland, grassland, water area, urban and rural industrial and mining land, and unused land and sea, each of which can be divided into several subcategories. Urban and rural industrial and mining residential land can be divided into urban land, rural residential land and other construction land. This study mainly discusses the relationship between carbon emissions and cultivated land, urban land, rural residential land and other construction land in each research area. The results show that there was a correlation between urban land area and carbon emissions in 2000 and 2005. In 2015, the carbon emissions of each study area were correlated with the area of rural residential land, and they were significantly correlated with other construction land.

The results above show that the carbon emissions of the research region are affected by the area of urban land, rural residential land and other urban construction land. However, the main influencing factors are different in different time periods. Before 2005, they were mainly affected by the urban land area. After 2015, they were mainly affected by the area of rural residential land and other construction land.

The reason for this phenomenon has to do with the industrial structure adjustment of Chengdu. With the development of the city, the factories and enterprises mainly engaged in the secondary industry in the city center have gradually been relocated. Some small enterprises simply withdrew from the secondary industry to engage in the tertiary industry. The early industry was mainly located in the eastern suburbs of Chengdu, such as the Chenghua District. Later, with the adjustment of the industrial structure, many large factories and enterprises were relocated and transformed, and Chengdu's industrial structure was reorganized. Ninety percent of enterprises involved in relocation have moved to the Longquanyi Chengdu Economic and Technological Development Zone, Xindu, Shuangliu and other areas. Each region has different priorities for industrial development. This also indirectly leads to the impact of carbon emissions in each region of Chengdu indirectly.

5.4 Relationship between Carbon Emissions and Economic Development

Research on the relationship between carbon emissions and economic development mainly focuses on

the analysis of the relationship between GDP and industrial GDP and carbon emissions in each research region. The results show a correlation between carbon emissions and GDP and industrial GDP in each region in 2000, 2010 and 2015. There was a significant correlation in 2000. The reasons for this phenomenon are mainly related to the economic structure of Chengdu. Despite many adjustments, Chengdu's current economic structure is still dominated by industry. The characteristics of industry-that determine Chengdu's economic growth are still relatively extensive. As a result, although the economic aggregate has grown, the quality and sustainability of the growth have not been effectively guaranteed. Second, it is the impact of the energy structure and energy efficiency in the process of economic growth. At present, the proportion of new energy and clean energy in Chengdu's energy structure is still not high. The energy utilization rate per unit is lower than that of major countries. Finally, changes in people's consumption habits brought by economic growth have also increased carbon emissions. As a result, in a certain period of time in the future, carbon emissions in Chengdu will still be positively correlated with economic development.

Table 1. Correlation Analysis of Carbon Emissions with Population, GDP and Land Use in 2000

		Carbon emissions	Population	Industrial GDP	GDP	
Carbon emissions	Pearson Correlation	1	.458*	.628**	.617**	
	Significance		.049	.004	.005	
		Cultivated land	Urban construction land	Rural residential land	Other land	construction
	Pearson Correlation	-.041	.515*	.031	-.097	
	Significance	.869	.024	.901	.691	

*. The correlation was significant at 0.05 level (two-tailed).

**. The correlation was significant at 0.01 level (two-tailed).

Table 2. Correlation Analysis of Carbon Emissions with Population, GDP and Land Use in 2005

		Carbon emissions	Population	Industrial GDP	GDP
	Pearson Correlation	1	.563*	.442	.418
	Significance		.012	.058	.075

Carbon emissions		Cultivated land	Urban construction land	Rural residential land	Other land	construction
	Pearson Correlation	.092	.506*	.219	.373	
	Significance	.707	.027	.368	.116	

*. The correlation was significant at 0.05 level (two-tailed).

**. The correlation was significant at 0.01 level (two-tailed).

Table 3. Correlation Analysis of Carbon Emissions with Population, GDP and Land Use in 2010

		Carbon emissions	Population	Industrial GDP	GDP	
	Pearson Correlation	1	.493*	.841**	.514*	
	Significance		.032	.000	.024	
Carbon emissions		Cultivated land	Urban construction land	Rural residential land	Other land	construction
	Pearson Correlation	.208	.380	.370	.352	
	Significance	.393	.108	.119	.216	

*. The correlation was significant at 0.05 level (two-tailed).

**. The correlation was significant at 0.01 level (two-tailed).

Table 4. Correlation Analysis of Carbon Emissions with Population, GDP and Land Use in 2015

		Carbon emissions	Population	Industrial GDP	GDP
	Pearson Correlation	1	.536*	.469*	.467*
	Significance		.018	.043	.044
		Cultivated land	Urban land	construction land	Rural residential land	Other construction land
Carbon emissions	Pearson Correlation	.265	.338	.472*	.776**	
	Significance	.273	.157	.041	.000	

*. The correlation was significant at 0.05 level (two-tailed).

**. The correlation was significant at 0.01 level (two-tailed).

5. Conclusion

This study uses geographic information system technology and Pearson correlation coefficient analysis to analyze the carbon emissions of 19 districts and counties in Chengdu. The characteristics of the temporal and spatial distribution and rules of carbon emissions in Chengdu are discussed. At the same time, the relationship between carbon emissions and population, the economy and land use in Chengdu is analyzed, and the causes of this phenomenon are discussed. We hope to provide some guidance for optimizing the urban spatial structure and protecting the ecological environment in Chengdu. The results show that the overall carbon emissions in Chengdu are increasing. However, since 2010, carbon emissions in central urban areas have decreased, and carbon emissions in other major carbon-emitting regions have also grown relatively slowly. Population, the economy and land use will all affect the carbon emissions of Chengdu, and the impact of land use will be different in different periods. Based on the research results, the above factors should be fully considered in the adjustment of the urban structure and the formulation of energy conservation and emission reduction policies in Chengdu in the future.

This study mainly provides a method of analyzing the characteristics of the distribution and laws of carbon emissions and the influencing factors, and it provides a relevant basis for future urban construction and policy making in Chengdu. In addition to the factors discussed in this paper, energy utilization efficiency, green area, residents' travel mode, the development and utilization of new energy and other factors will affect urban carbon emissions. Follow-up research can be carried out on this basis.

References

Hou, Q. H., Zhang, X., Li, B., Zhang, X. Q., & Wang, W. H. (2019). “Identification of Low-Carbon Travel Block Based on GIS Hotspot Analysis Using Spatial Distribution Learning Algorithm.” *Neural Computing and Applications*, *31*(9), 4703-4713. https://doi.org/10.1007/s00521-018-3447-8

Huang, Y., Xia, B., & Yang, L. (2013). Relationship Study on Land Use Spatial Distribution Structure and Energy-Related Carbon Emission Intensity in Different Land Use Types of Guangdong, China, 1996-2008. *The Scientific World Journal*, *2013*(2004). https://doi.org/10.1155/2013/309680

Jiang, J. H. (2016). China’s Urban Residential Carbon Emission and Energy Efficiency Policy. Energy, *109*, 866-875. https://doi.org/10.1016/j.energy.2016.05.060

Kokotsaki, D., Menzies, V., & Wiggins, A. (2014). Low Carbon Transitions and the Reconfiguration of Urban Infrastructure Abstract. *Critical Studies on Security*, *2*(2), 210-222.

Liu, B. Y., Martin, H., Anders, S., & Chen, W. D. (2015). Effects of Carbon Emission Regulations on Remanufacturing Decisions with Limited Information of Demand Distribution. *International Journal of Production Research*, *53*(2), 532-548. https://doi.org/10.1080/00207543.2014.957875

Shan, Y. L., Guan, D. B., Zheng, H. R., Ou, J. M., Li, Y., Meng, J., Mi, Z. F., Liu, Z., & Zhang, Q.

(2017). Data Descriptor: China CO 2 Emission Accounts. *Scientific Data*, 1-14. https://doi.org/10.1038/sdata.2017.201

Shan, Y. L., Huang, Q., Guan, D. B., & Klaus, H. (2020). "China CO2 Emission Accounts 2016-2017." *Scientific Data*, *7*(1), 1-9. https://doi.org/10.1038/s41597-020-0393-y

Shen, X. Z., Huang, L., Zhu, J., & Gao, J. J. (2021). Relationship between Land Use Carbon Emission and Economic Growth Based on GIS. *Arabian Journal of Geosciences*, *14*(6). https://doi.org/10.1007/s12517-021-09181-x

Vinuya, F., Ferdinand, D., & Erica, S. (2010). A Decomposition Analysis of CO2 Emissions in the United States. *Applied Economics Letters*, *17*(10), 925-931. https://doi.org/10.1080/00036840902762688

Wang, S. J., Gao, S., Huang, Y. Y., & Shi, C. Y. (2020). Spatio-Temporal Evolution and Trend Prediction of Urban Carbon Emission Performance in China Based on Super-Efficiency SBM Model. *Dili Xuebao/Acta Geographica Sinica*, *75*(6), 1316-1330.

Wang, X. P., Feng, Q., & Song, J. Z. (2020). The Spatial Association Structure Evolution of Carbon Emissions in Chengdu-Chongqing Urban Agglomeration and Its Influence Mechanism. *China Environmental Science*, *40*(9), 4123-4134.

Wang, Z. J., Chen, F., & Taku, F. (2015). Carbon Emission from Urban Passenger Transportation in Beijing. *Transportation Research Part D: Transport and Environment*, *41*(3), 217-227. https://doi.org/10.1016/j.trd.2015.10.001

PENG, W. F., ZHOU, J. M., XU, X. L., LUO, H. L., ZHAO, J. F., & YANG, C. J. (2017). Effect of Land Use Changes on Carbon Emission and Its Spatial Patterns in Chengdu Plain and Its Surrounding Area, Western China, from 1990 to 2010. *Ecological Science*, *36*, 105-114.

Wu, D. E., John, C. L., Tomohiro, O., & Eric, A. K. (2020). Space-Based Quantification of per Capita CO2 Emissions from Cities. Environmental Research Letters, *15*(3). https://doi.org/10.1088/1748-9326/ab68eb.

Ye, H., Xiao, Y. H., Yu, S., Li, X. H., Zhang, G. Q., Lin, T., & Xiao, L. S. (2015). A Sustainable Urban Form: The Challenges of Compactness from the Viewpoint of Energy Consumption and Carbon Emission. *Energy and Buildings*, *93*, 90-98. https://doi.org/10.1016/j.enbuild.2015.02.011

Zhang, B., Gao, D. X., Gao, J. X., & Yang, Y. (2014). The Cooling Effect of Urban Green Spaces as a Contribution to Energy-Saving and Emission-Reduction: A Case Study in Beijing, China. *Building and Environment*, 76, 37-43. https://doi.org/10.1016/j.buildenv.2014.03.003

Zhang, X. (2018). "Spatial-Temporal Differences and Driving Factors of Carbon Emission from Energy Consumption in China." *ARID LAND GEOGRAPHY*, *41*(5), 1115-1122.

Zhao, Y. T., Huang, X. J., Zhong, T. Y., & Peng, J. W. (2011). Spatial Pattern Evolution of Carbon Emission Intensity from Energy Consumption in China. *ENVIRONMENTAL SCIENCE*, *32*, 5-12.