Study on the Relationship Between Urban Services Facilities and Carbon Emissions in Guangzhou Based on Multi-Source Data

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Abstract: Large cities are often faced with serious carbon emission problems caused by rapid urban expansion, and it is urgent to optimize urban services facilities while achieving energy conservation and emission reduction. Based on the original point text data of various service facilities in Guangzhou and the grid data of monthly average carbon emissions in 2022, this study explores the relationship between urban services facilities and carbon emissions in Guangzhou by using spatial autocorrelation method and Geodetector.The results show that urban carbon emissions are closely related to the spatial distribution of urban services facilities, and traffic service facilities have the greatest influence on the spatial distribution of urban carbon emissions. Based on these research findings, corresponding recommendations and measures for effectively reducing carbon emissions in the development of urban service infrastructure are proposed.

Key words: Urban Services Facilities; Carbon Emissions; Spatial Distribution

1. Introduction

With the increasingly severe global climate change and energy crisis, reducing carbon emissions has become a common goal of the international community. China is actively taking actions to address climate change and promote the development of a green and low-carbon economy, and has made a commitment to achieve the peak of carbon dioxide emissions by 2030. As one of the country's first-tier cities, Guangzhou is experiencing a rapid urbanization process. However, with the acceleration of the construction of urban services, carbon emissions have also increased, which not only exacerbates the urban heat island effect, but also has a negative impact on air quality, which in turn threatens the sustainable development of cities.

This study focuses on Guangzhou's urban area, utilizing Baidu Map POI data and open-source anthropogenic CO2 emissions data. By employing Geographic Information System (GIS) and Geodetector tools, the study analyzes the distribution patterns of urban service facilities and carbon emissions. Spatial autocorrelation and Geodetector are used to investigate the correlation between these distributions.From the perspective of urban service facilities, this study fills the gap in the field of urban carbon emission research, and provides suggestions for strengthening urban services while promoting the construction of low-carbon cities.

2. Literature Review

Currently, there are few studies examining the correlation between urban service facilities and the distribution of carbon emissions. However, there is extensive research on the spatial patterns of carbon emissions within cities and regions.Sun Yudong et al. used the gop-plus model to simulate the distribution of land use change and carbon emissions under different scenarios.[1].The research of Zhou Hang and others shows that the carbon emissions at the county scale in Hunan Province show obvious spatial differentiation characteristics, and the key factors affecting county carbon emissions are revealed through Geodetector and spatio-temporal weighted regression model[2]. The research of Zhang Zhiyang and others analyzed the spatial pattern and coordinated zoning of county land use carbon emissions in Hebei Province by constructing a carbon emission evaluation model, and revealed the economic contribution and ecological carrying capacity of carbon emissions in different regions [3].The research of Xu Jiajun and others explored the spatiotemporal characteristics of carbon emissions of urban residents in China and the spatiotemporal heterogeneity of its influencing factors through map visualization and spatial autocorrelation [4].The research of Zhang Yao and others used the night light data of Luojia-1 and the energy statistics data of Xi'an, Combined with the high-low clustering model, the carbon emission of Xi 'an in 2018 was simulated, and the carbon emission intensity of each district and county was calculated.[5].Wang Jing et al. constructed a carbon effect assessment index system based on vegetation cover type and land use type, and used remote sensing data to assess the annual carbon emissions and carbon absorption of Beijing-Tianjin-Hebei metropolitan area, and analyzed its spatial distribution characteristics[6]. Li Yixian's research discussed the factors affecting the spatial pattern of carbon emissions in Wuhan metropolitan area, and put forward the low-carbon spatial planning strategy[7].The research of Qi Qiangqiang et al. estimated the carbon emissions of the Yellow River Basin from 2000 to 2019 through the long-term series of night light data, and explored the influencing factors of carbon emission[8]. Lin Xuezhuang's research explores the use of night light data to analyze the carbon emission distribution characteristics of construction land in Guangxi[9].The research of Zhang Jingni and others analyzed the spatial variation characteristics and spatial agglomeration characteristics of carbon emission in Shaanxi Province from 2000 to 2017[10].

3. Data and methodology

3.1 Overview of the Research Area

In this paper, Guangzhou is taken as the research object, covering the central area (including Tianhe, Yuexiu, Haizhu, Liwan, Baiyun, Huangpu District), Conghua District, Zengcheng District, Huadu District, Panyu District (including Nansha District), to explore the internal relationship between urban services facilities and urban carbon emissions.

3.2 Research Data Source

The administrative boundary data comes from the official website of the National Fundamental Geographic Information Center (www.ngcc.cn), and the administrative divisions of Guangzhou are obtained by tailoring. The POI data of various service facilities are from Baidu Map. The original point text data of various service facilities with longitude and latitude coordinates are obtained from Baidu Map, and the text data are converted into vector point data for research and analysis in ArcGIS software, as shown in Figure 1.

This paper uses 13 types of urban service , including health care service facilities, indoor facilities, living service facilities, business residence, car sales facilities, car repair facilities, car service facilities, motorcycle service facilities, transportation service facilities, accommodation service facilities, companies and enterprises, public facilities, food and beverage service facilities as research objects.

Carbon emissions data are from ODIAC.The monthly average ODIAC data in 2022 is preprocessed by cutting, projecting, merging and converting the grid to the surface to obtain the spatial distribution of annual average carbon emissions in Guangzhou in 2022.

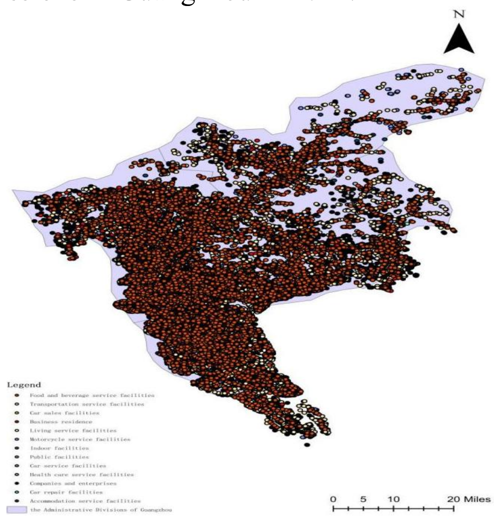

Figure 1. Implementation of Various Urban Services in Guangzhou

3.3 Research Methods

3.3.1 Spatial autocorrelation analysis

Spatial autocorrelation is a method to study whether a variable is spatially correlated and the degree of correlation. It mainly focuses on the dependence between observations in spatial data and observations in their neighboring locations. Through the analysis of spatial autocorrelation, we can identify the agglomeration characteristics, hot spots and cold spots of spatial data, and then reveal the spatial distribution rules and patterns.In this study, GeoDa software was used to perform bivariate local autocorrelation analysis (Moran's I) to reveal the spatial distribution relationship between various urban service facilities and urban carbon emissions. Using LISA statistics and their significance tests, the spatial patterns are categorized into high-high, high-low, low-high, and low-low clusters.

3.3.2 Geodetector

GeoDetector is a method used to analyze variability and drivers in geospatial data. By analyzing the influence of independent variables on the spatial distribution of dependent variables, geodetectors can help identify key factors influencing a phenomenon and their mechanisms of action.

Factor detection:Determine which factors have a significant impact on the spatial differences in the outcome variables. By calculating the Q value (explanatory power index) for each factor, it is possible to determine which factors have a significant effect on the spatial distribution of the outcome variable.The formula is as follows:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \quad (1)$$

Where H is the stratification of the variables, N_e and N are the number of cells in layer H and global, respectively, σ_h^2 and σ^2 are the variances in layer H and carbon emission Y values, respectively.

Interaction detection:Reveal the comprehensive influence strength of different factors combined on the study object. If two or more factors have limited explanatory power when acting alone, but can significantly improve the explanatory degree of the spatial distribution of the result variables under the combined action, it indicates that there is a strong interaction effect between these factors.

4. Results and Discussion

4.1 Distribution of Urban Services Facilities in Guangzhou

All service facilities were merged using GIS tools, and Kernel Density Estimation was applied to illustrate their distribution, as shown in Figure 2. The results indicate a high concentration of facilities in the central area, with density decreasing outward.

Urban service facilities also reflect regional development levels. In Guangzhou, the distribution aligns with the GDP-based development tiers of administrative districts:The first ladder: The middle of the central area; the second ladder: The area around the central area, Huadu District, Panyu District; Third ladder:Outside the central area[11].The comprehensive distribution characteristics of urban services facilities are in line with the distribution law found in the existing research on health care service facilities. The urban service facilities in the central area show a distribution trend of "high in the west and low in the east" and "high in the south and low in the north", and have a significant feature of gradual decrease from the city center to the edge[12].

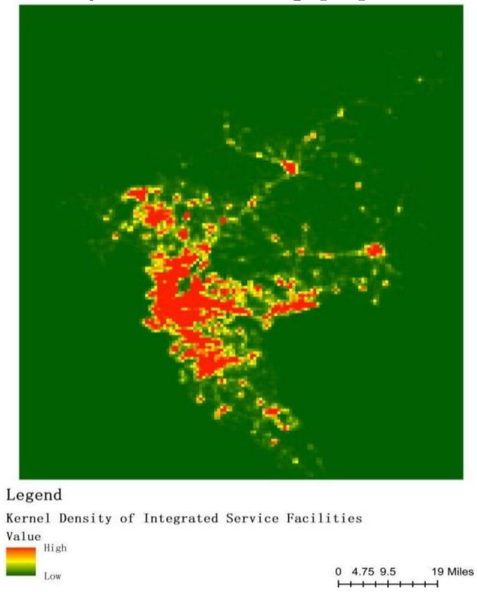

Figure 2. Comprehensive Distribution of Urban Services Facilities

Based on the different types of urban services facilities obtained, their respective distribution can be obtained through Kernel Density Estimation, as shown in Figure 3.

The distribution of urban services facilities in Guangzhou can be divided into the following categories:①The distribution of car sales service, companies and enterprises service, car service, life service, food and beverage service and accommodation service facilities is very similar, which are concentrated in the central area and form a certain scale in the north of Panyu District and the middle of Huadu District.②Health care service facilities， motorcycle service facilities and public facilities are mainly concentrated in the central area, and a small number of them are concentrated in other areas.③The transportation service facilities, business residence are mainly distributed in the central area and the north of Panyu District, with sporadic gathering in other districts.

Despite differences in distribution, all service facilities are highly concentrated in central area, with many facilities clustered in central Huadu District and northern Panyu District, though less so than in the city center. Service facilities in Zengcheng District and Conghua District show small-scale or sporadic aggregations, exhibiting the lowest concentration levels in Guangzhou.

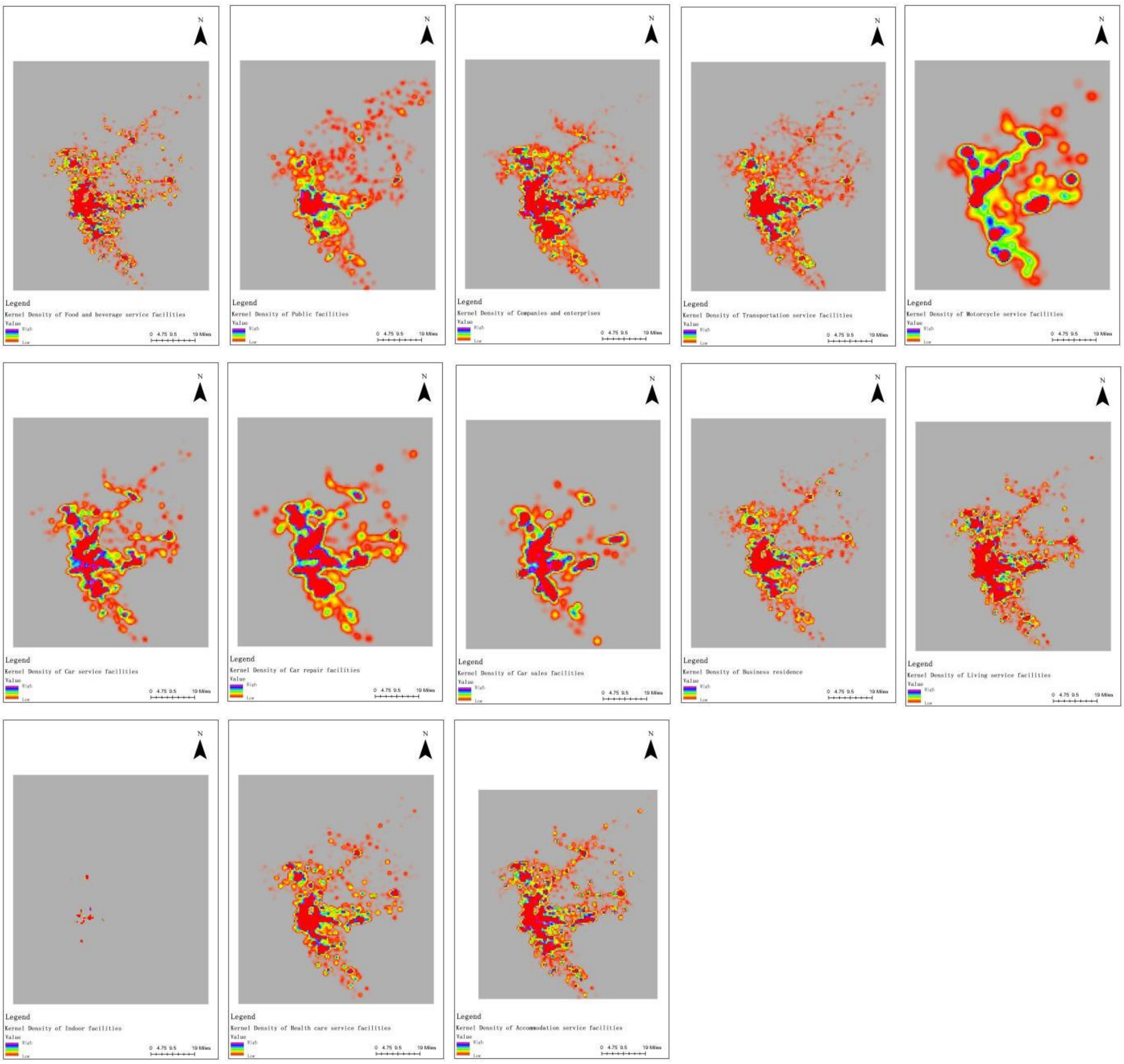

Figure 3. Kernel Density of Various Urban Services facilities

4.2 Analysis of the Correlation Between Urban Carbon Emissions and Service Facilities

4.2.1 Spatial Distribution of Carbon Emissions in Guangzhou

The grid data of carbon emissions in the whole year and 12 months of Guangzhou in 2022 are averaged, and the results are divided into 8 categories by the natural breakpoint method to obtain the annual average spatial distribution of carbon dioxide emissions in Guangzhou, as shown in Figure 4.

Through the results of natural breakpoint method, it can be found that the carbon emissions in Guangzhou generally show a spatial distribution trend of high in the middle and low in the periphery. The high value area is located in the middle of the central area, and the carbon emission intensity decreases from the middle of the central area to the surrounding areas, while Conghua District and Zengcheng District

have large areas of low value areas. Combined with the comparison of satellite images, it is found that the abnormal high value areas are the locations of large power plants.

4.2.2 Analysis of correlation between urban service facilities and carbon emission distribution

In this paper, a 1km×1km fishing net was created in the study area, and the basic unit of the study was obtained after tailoring. The number of different types of service facilities in each grid is calculated, and the frequency and carbon emission intensity value of each grid corresponding to each type of service facilities are obtained. The spatial autocorrelation analysis (bivariate Moran index) in GeoDA is used to calculate the connection degree between various urban services facilities and the spatial distribution of carbon emissions, and visualize the autocorrelation relationship between various urban services facilities and the spatial distribution of urban carbon emissions, as shown in Table1 and Figure 5.(join_Count represents the number of city services in each grid, and district represents carbon intensity)

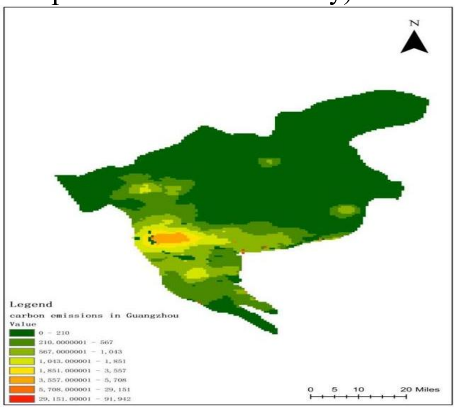

Figure 4. Average annual Spatial Distribution of Carbon Emissions in Guangzhou

Table 1. Moran's I of Urban Services Facilities and Carbon Emissions

Type	Moran's I
Health care service facilities	0.446
Indoor facilities	0.222
Living service facilities	0.261
Business residence	0.353
Car sales facilities	0.210
Car repair facilities	0.265
Car service facilities	0.127
Motorcycle service facilities	0.098
Transportation service facilities	0.438
Accommodation service facilities	0.428
Companies and enterprises	0.182
Public facilities	0.509
Food and beverage service facilities	0.255

By comparing the relationship between the spatial distribution of different urban service facilities and urban carbon emissions, it is found that public facilities (Moran's I = 0.509) show the most significant spatial autocorrelation. This indicates that the spatial distribution of public facilities has a significant difference inthe correlation between different urban service facilities in terms of urban carbon emissions. The results show that the urban service system includes many parts, which have different influence mechanisms on carbon emission.

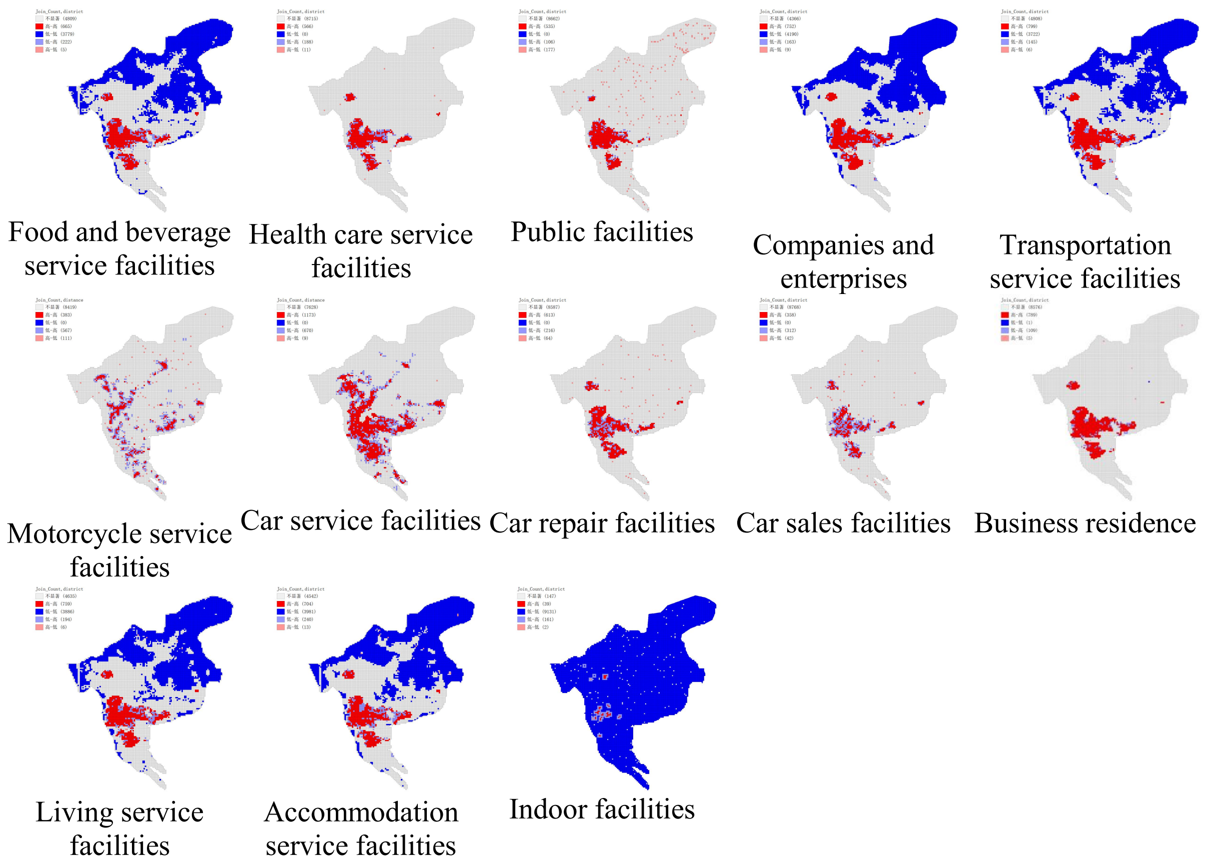

Figure 5. LISA Cluster Diagram of Urban Services Facilities and Carbon Emissions

The spatial distribution of urban service facilities and carbon emissions in Guangzhou primarily shows high-high clusters in the central area, particularly in the middle of the central district, which is the most prosperous core with dense high-rise buildings and various services. This area has a large population and high carbon emission intensity.

Small-scale high-high clusters of urban service facilities are also present in the north of Panyu District and the middle of Huadu District.These regions have a long history of development, diverse infrastructure, high population density and intensive production activities make carbon emission intensity not low.

Food and beverage, company, transportation, living, and accommodation service facilities show low-low clusters with carbon emissions in areas outside the central district, especially in the marginal regions. Areas outside the central district have less developed infrastructure and smaller populations, with particularly significant low-low clusters in Zengcheng District and Conghua District, which are far from the central area.

Low-high clusters are common in the peripheral areas of the central district, where infrastructure development is lower and service facility density is less than in the downtown area. Despite this, these peripheral areas remain part of the urban built-up area with intensive production activities and high carbon emissions.

4.3 Research on Influencing Factors of Spatial Distribution of Urban Carbon Emissions

This paper aims to explore the impact mechanism of various service facilities on the spatial distribution of urban carbon emissions and uses the counts of 13 types of urban service facilities within each grid as independent variables, carbon emissions per grid serve as the dependent variable.The paper analyzes the impact of these facilities on carbon emissions by inputting the variables into the Geodetector to yield factor detection and interaction detection results.

In the factor detection results (Table 2), all factors passed the hypothesis test at the 5% level, with p-values below 1%, indicating extremely significant differences. The Q value reflects the explanatory power of different service facilities for urban carbon emissions, where a higher Q value signifies greater explanatory power. Table 1 shows the degree of explanation for different types of urban service facilities on urban carbon emissions as follows: transportation service facilities (X9) > business residence(X4) > public facilities (X12) > health care service facilities (X1) > Food and beverage service facilities (X13) > living service facilities (X3) > companies and enterprises (X11) > accommodation service facilities (X10) > car service facilities (X7) > car repair facilities (X6)> car sales facilities (X5) > indoor facilities (X2) > motorcycle service facilities (X8). Transportation services (Q = 0. 350) explained the highest carbon emissions, followed by business residence(Q = 0. 344) and public facilities (Q = 0. 299). The transportation sector is a primary contributor to carbon dioxide emissions in China. With the increase of motor vehicle ownership, the low-carbon transformation of transportation service facilities is very important[14].Based on the full text study,there is a close relationship between carbon emissions and transportation service facilities in Guangzhou, indicating that future studies on urban carbon emissions in Guangzhou can focus more on the field of transportation service facilities, and relevant urban planning departments need to link the construction of transportation service facilities with energy conservation and emission reduction more often.

Table 2. Factor Detection Results

Variables	Type	q	p
X1	Health care service facilities	0.28703051	2.97E-10
X2	Indoor facilities	0.05847795	8.44E-10
X3	Living service facilities	0.26281916	2.01E-10
X4	Business residence	0.34433187	3.31E-10
X5	Car sales facilities	0.08010058	2.72E-10
X6	Car repair facilities	0.10948743	5.76E-10
X7	Car service facilities	0.18574731	2.42E-10
X8	Motorcycle service facilities	0.04737438	6.77E-10
X9	Transportation service facilities	0.3503394	7.38E-10
X10	Accommodation service facilities	0.23897409	2.59E-10
X11	Companies and enterprises	0.2532591	4.06E-10
X12	Public facilities	0.29900006	7.01E-10

4.4 Detection of the Interaction of Urban Services Facilities on the Spatial

Characteristics of Carbon Emissions

In the interaction detection analysis (Figure 6), the main interaction types are two-factor enhancement (Enhance, bi-) and nonlinear enhancement (Enhance, nonlinear -), indicating that when two or more facility types function simultaneously, their ability to account for carbon emissions is significantly improved. The interaction between motorcycle service facilities (X8) and traffic service facilities (X9) has the highest explanatory power (Q=0.4164891). This result suggests that, when considering carbon emissions, the combined effect of motorcycle service facilities and transportation service facilities can explain the spatial distribution of carbon emissions more accurately than when they act separately. Some facility types with weak explanatory power in single-factor analysis have significantly improved their explanatory power when interacting with other facility types. For example, the explanatory power of the motorcycle service facility (X8) is only 0.04737438 when it acts alone, but increases to 0.4026036 when it interacts with the commercial and residential facility (X4).

There are three main reasons why these interactions can enhance the explanatory power of carbon emissions: the interaction between different facility types may produce synergistic effects, resulting in the spatial distribution of carbon emissions becoming more complex and unpredictable, so that when multiple facility types are considered at the same time, this complexity can be more fully captured, thus improving the explanatory power; Some facility types may have a weak impact on carbon emissions in some areas, but when combined with other facility types, they can complement each other and jointly have a significant impact on carbon emissions. The complementary effect generated in this process enhances the explanatory power under the interaction. The relationship between carbon emissions and certain facility types is nonlinear, so considering the type of nonlinear enhancement in the interactive detection can more accurately capture this nonlinear relationship, thus further improving the explanatory power.

Show that from the perspective of urban services facilities, there is a complex mechanism of urban carbon emissions, which is the result of the interaction of various urban services facilities.

X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
Health ca	Indoor fac	Living ser	Business r	Car sales	Car repai	Car servic	Motorcycl	Transport	Accommc	Companies	Public fac	Food and beverage service facilities

0.38274												0.361666	X12
											0.36208	0.3017395	X11
0.351173										0.287896	0.348203	0.2788922	X10
									0.360899	0.388786	0.384026	0.3683276	X9
0.300089								0.4164891	0.3053	0.29342	0.349095	0.3684422	X8
							0.266078	0.3827402	0.253446	0.290022	0.351173	0.2982387	X7
						0.208049	0.164294	0.3749526	0.265765	0.307186	0.327107	0.2971607	X6
0.271502					0.143297	0.194752	0.166639	0.361433	0.246247	0.287875	0.315526	0.278779	X5
				0.361134	0.375425	0.384085	0.402604	0.3740817	0.358243	0.36923	0.39146	0.364953	X4
0.253446			0.356192	0.271502	0.28373	0.285875	0.312988	0.3664285	0.274956	0.302697	0.357917	0.2801201	X3
		0.291653	0.348843	0.126102	0.150256	0.21079	0.106799	0.3429327	0.262548	0.263366	0.294984	0.2866742	X2
0.106799	0.300089	0.301628	0.36793	0.295833	0.310606	0.325189	0.386088	0.3699561	0.295019	0.322485	0.362603	0.2918451	X1
	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	

Figure 6. Interaction Detection Results

5. Research Conclusions

This study analyzes the distribution characteristics of urban carbon emissions and various types of urban service facilities in Guangzhou, and explores the impact of different types of urban service facilities on carbon emissions.It finds that public service facilities have the highest spatial autocorrelation with carbon emissions, and all facilities are positively correlated with carbon emissions. High-high clustering is observed centrally and in parts of Panyu and Huadu Districts, while low-low and low-high clustering appear outside the central area and in the central margins, respectively.Factor detection results indicate that transportation service facilities have the highest degree of explanation for the spatial distribution of urban carbon emissions.Interaction detection results indicate that the interaction between motorcycle and traffic service facilities has the highest explanatory power for carbon emissions, with motorcycle services showing the most significant improvement.

The following is a further detailed introduction of the specific ways that various urban service facilities affect carbon emissions:1.transportation service facilities, and car sales facilities, car repair facilities, car service facilities, The operation of motorcycle service facilities involves the use and maintenance of vehicles. These activities will generate a lot of carbon emissions, especially the burning of fossil fuels. 2. In the construction of health care service facilities, indoor facilities, living service facilities and other buildings, a large number of building materials will be used, such as cement, steel, etc. The production and use of these materials produce carbon emissions. 3. During the construction and operation of business residence, not only will a lot of energy and materials be consumed during the construction stage, but also during the operation process, food and beverage service facilities use energy in the cooking process, while food storage, processing and waste also generate carbon emissions. 5.public facilities such as parks and squares also consume energy and materials in the construction and maintenance process, thus generating carbon emissions. 6.companies and enterprises consume energy and generate carbon emissions in their daily operations, such as office work and production. 7. When accommodation service facilities provide services, they need to consume energy for heating, cooling, lighting, etc. These activities will also generate carbon emissions.

Based on these findings, traffic service facilities significantly influence Guangzhou's urban carbon emissions.In order to achieve the effect of energy saving and carbon emissions reduction, the future construction of urban service facilities can focus more on the optimization of traffic service facilities.Here are some feasible directions: Urban planners should consider developing comprehensive public transportation systems to improve their efficiency and accessibility, reducing citizens' dependence on private cars; promote green travel modes such as the construction of bike lanes and pedestrian paths to encourage citizens to adopt low-carbon travel modes; optimize urban layout through intelligent traffic systems to reduce traffic congestion; design smart parking systems to reduce the time spent by vehicles searching for parking spaces, thereby lowering carbon emissions; use permeable and permeable paving materials to build eco-friendly parking lots, reducing the urban heat island effect.In addition, although public service facilities and service facilities based on the tertiary industry are not direct sources of urban CO2 emissions, their layout and scale have an important impact on the lifestyle and travel patterns of urban residents, and thus indirectly affect carbon emissions. It is suggested that in the construction of public service facilities, attention should be paid to the rationality of their layout, and the centralized and balanced service facilities should be realized as far as possible, so as to meet the travel needs of residents and reduce unnecessary carbon emissions at the same time.

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