Article

Not peer-reviewed version

Development Strategy Based on Combination of Carbon Emission and Vibrancy Typology — a Multi-sourced Data-Driven Approach in Beijing, China

Jingyi Xia , Jiali Wang , Yuan Lai *

Posted Date: 24 May 2024

doi: 10.20944/preprints202405.1585.v1

Keywords: Carbon emissions; Urban vibrancy; Development strategy

Article

Development strategy based on combination of carbon emission and vibrancy typology — A multi-sourced data-driven approach in Beijing, China

Jingyi Xia, Jiali Wang and Yuan Lai *

Department of Urban Planning and Design, School of Architecture, Tsinghua University, Beijing 100084, China; xiajy23@mails.tsinghua.edu.cn (J.X.); wangjial19@mails.tsinghua.edu.cn (J.W.)

* Correspondence: yuanlai@tsinghua.edu.cn

Abstract: Confronting the dual challenges of rapid urbanization and climate change, although extensive research has investigated the influencing factors and practical strategies of urban carbon emissions and urban vibrancy, respectively, the unclear mutual nexus between them and the development strategy of collaborative optimization requires further in-depth analysis. This study explores the delicate balance between urban vibrancy and low-carbon sustainability within the confines of Beijing's Fifth Ring Road. By integrating OpenStreetMap, land use, population, and building carbon emission data, we have developed a reproducible method to estimate total carbon emission and emission intensity per capita. Furthermore, we have introduced vibrancy index data to distinguish the vibrancy evaluation of residential and non-residential land and applied cross-combinational classification technology to dissect the spatial correlation between urban carbon emissions and urban vibrancy. The results reveal that the four combination typologies show more significant differences and regularity in residential land. Based on the discovery of spatial correlation, this study puts forward corresponding development strategy suggestions for each typology based on geographical location and the requirements of urban development policies of these four combination typologies. In conclusion, our study highlights the importance of integrating carbon emissions and urban vibrancy comprehensively in sustainable urban planning and proposes that various land use combinations need targeted development strategies to achieve this goal, which need to consider population, energy, service facilities, and other diverse aspects.

Keywords: carbon emissions; urban vibrancy; development strategy

---

1. Introduction

As global climate change intensifies and urbanization accelerates, the issue of "urban disease" has become increasingly conspicuous in the major cities of China [1]. Historically, a development paradigm prioritizing speed over quality has led to significant challenges, including excessive carbon consumption and elevated carbon emissions. Moreover, this mode has also resulted in a development impasse where some regions need help maintaining urban vibrancy, showing a monotonous style of thousands of cities [2]. In 2022, the United Nations Human Settlements Programme (UN-Habitat) released the World Cities Report, which underscored the necessity for cities to invest in green initiatives aimed at fostering sustainable consumption and production patterns and steer the global community towards a future characterized by resilience, equity, and sustainability. In addition, the report also suggests that cities and local governments should give priority to infrastructure investment in order to build a resilient urban economy and a prosperous urban future [3]. Thus, the pursuit of low-carbon sustainability and the enhancement of urban vibrancy represent critical opportunities and challenges in the development of future human settlements. In view of the fact that many human settlements activities are not only directly related to urban carbon emissions, but also the key elements to shape urban vibrancy, there are sometimes conflicts and contradictions between these two goals due to the influence of the same factors. Therefore, delving into the interplay and interconnection between carbon emissions and urban vibrancy and seeking balance and optimization between these two goals is really crucial for the construction of future cities that are not only sustainable but also livable and vibrant.

 doi:10.20944/preprints202405.1585.v1

The term "co-benefit" was first introduced in the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report in 2001, referring to the benefits of policies encompassing climate change mitigation and pollution reduction. Such co-benefits acknowledge that many policies mitigating greenhouse gases pursue other equally important objectives [4]. In 2014, the IPCC Fifth Assessment Report redefined co-benefit as "the positive outcomes that a policy or measure, aimed at one target, may have on other targets, without considering the net impact on overall societal welfare" [5]. This concept underscores the potential for climate actions to yield mutual benefits, thereby enhancing their overall value and appeal to policymakers and the public, and at the same time, extends the concept of co-benefit to other fields. Cities as complex giant systems encompass various sectors such as transportation, energy, architecture, and environment, along with multiple subsystems including natural, social, and human systems [6,7]. These domains and systems interact based on shared physical spaces, human activities, and data [8], generating relevant co-benefits. By adjusting these common influencing factors, urban planners can simultaneously optimize the two goals of urban carbon emissions and urban vibrancy. The key to realizing these co-benefits lies in identifying areas with co-benefits potential and formulating strategies according to specific characteristics.

This study explores the spatial organization relationship between urban carbon emissions and urban vibrancy and corresponding optimization strategies. Integrating multiple data sources in Beijing, it estimates lot-level carbon emissions and analyzes their relationship with land use types, local population, facility density, street quality, and other factors. Furthermore, this study investigates various planning strategies for future community development according to combinations of carbon emission intensity and urban vibrancy.

The rest of the paper proceeds in the following order: The literature review summarizes quantification methods for estimating urban carbon emissions and vibrancy and previous findings on the nexus between these two phenomena. The data and methods section describes the study area, data sources, data integration, carbon estimation, and classification process regarding the local carbon emissions and vibrancy. The results section summarizes major findings along with our interpretations of the carbon-vibrancy combination in the context of urban planning. Finally, the discussion section elaborates on planning considerations and strategies for future low-carbon urban development.

2. Literature Review

2.1. Quantifying Urban Carbon Emission

Carbon neutrality has become a global consensus for future development, and reasonable quantification methods are required to estimate carbon emissions and guide low-carbon practices. By the end of the 20th century, countries had actively explored carbon emission measurement methods and contributed growing research insights [9]. In general, urban carbon emission estimation relies on two observation subjects, either activity (e.g., building, transportation, production) or gas emissions (e.g., carbon dioxide, methane) [10]. The former method is widely used in urban planning. In this field, scholars usually use top-down or bottom-up methods to measure the temporal and spatial patterns of urban carbon emissions. Specifically, the top-down method calculates the total carbon emissions at the national or regional level through satellite remote sensing data. Then, it estimates the proximate city-level emissions based on land area, population density, or land value [11]. In comparison, the bottom-up approach measures carbon emissions within each sub-sector and then sums up the overall emissions based on certain spatial units [12]. Both of these methods need to consume a lot of manpower and material resources, which requires very high data openness and accessibility, and are too complicated for scholars who need to use carbon emission calculation results to assist research. Therefore, this paper hopes to develop a simple approximate method based on land use and building types to calculate the carbon emissions of urban functional plots.

From the perspective of factors affecting urban carbon emissions, many scholars have researched the influence of urban forms, such as concentrated population and polycentric structure [13]. Furthermore, in 2020, Huo et al. discussed the impact of urbanization on urban carbon emissions and pointed out the negative contribution of urban population and urban construction area to urban construction carbon emissions [14].In 2021, from the dimension of behavior, Wang et al. put forward the influence of individual consumption behavior of various products or services on carbon emissions [15]. It can be seen from previous studies that some variables affecting urban carbon emissions are also related to human activities, such as population structure and consumption behavior, which directly affect urban vibrancy.

The traditional carbon estimation method not only needs a large amount of data, but also has limitations in its generalization. Building carbon emission is a key part of urban carbon emission, and building is a key factor affecting urban carbon emission. Previously, some scholars have also tried to use building data to estimate urban carbon emissions [16,17]. Therefore, it is of a certain reference value for the researches in related fields to develop a method to establish the carbon emission baseline of urban buildings with limited and accessible building data. This method is simple and reproducible, which provides a new tool for approximately calculating the urban carbon emissions.

2.2. Nexus between Urban Vibrancy and Carbon Emission

The concept of urban vibrancy emerged from Jacob's observation of urban activities and human interactions in cities in the 1960s [18]. Urban vibrancy has evolved from describing the initial single-dimensional street life to representing multi-dimensional vitality involving living, working, and leisure activities [19]. Since the late 1990s, more scholars have established quantitative measurements for urban vibrancy by utilizing increasing available data and computing power. So far, the previous studies have explored urban data from heterogeneous sources, such as points of interest (POI) [20], mobile phone signaling [21], and geo-tagged social media [22]. Such data-driven quantitative measures reveal urban vibrancy's spatial and temporal characteristics from different dimensions.

From the perspective of factors that influence urban vibrancy, by dividing cities into districts, some scholars deeply explored and discovered that factors such as the socio-economic conditions, geographical location, and accessibility of each district had varying scales of impact on urban vibrancy [23]. With the continuous advancement of big data technology and the increasing availability of multi-source data, researchers have begun to focus on more detailed scales to investigate the specific role of the built environment in enhancing urban vibrancy. For instance, Lu et al. conducted a comparative analysis of community vibrancy in Beijing and Chengdu. They found a significant positive correlation between the diversity of Points of Interest (POIs), the accessibility of public transportation, and community vibrancy [24]. However, the impact of density indicators shows noticeable differences across cities at different levels of development. In 2024, taking Munich, Germany as an example, Gao et al. concluded that the density of POIs, building density, and the density of road intersections had a significant positive effect on urban vibrancy, while the impact of mixed land use is relatively negligible[25].

Recent research on urban vibrancy has increasingly focused on understanding the dynamic interplay between urban form and sustainability, particularly how it influences social cohesion and environmental health. Innovations in methodology, such as the use of geographic big data by Liu and Shi and taxi trajectory analysis by Zhang et al., have highlighted the significant impact of urban spatial structures on vibrancy [26,27]. These studies have revealed that well-planned urban designs not only enhance social interactions but are also crucial in promoting sustainable urban environments. Furthermore, Zikirya et al. introduces new perspectives by assessing urban vibrancy through daily activities, such as food takeaway services, illustrating how everyday urban functions are integral to the vibrancy of city life [28]. Increasing studies suggest that urban carbon emissions deeply connect to local vibrancy. Thus, an integrated urban planning approach is key to achieving vibrant and sustainable cities. This holistic approach underscores the necessity of aligning urban development with environmental goals to foster lively and sustainable urban spaces.

Previous researches indicate urban vibrancy as a collection of human activity intensity, the diversity of land-use configurations, and the accessibility of places, which is also a core element affecting urban carbon emissions [29–33]. Since similar factors drive urban vibrancy and carbon emissions, analyzing their correlation and interactions is necessary. Numerous scholars have targeted the development stages and characteristics of different cities, employing a variety of indicators and methods to identify potential influencing factors on the single dependent variable of urban carbon emissions or urban vibrancy. The research has made remarkable progress in these fields and yielded many far-reaching findings. However, although urban carbon emissions and urban vibrancy are key factors affecting cities' health and sustainable development, few studies have combined them to explore their interplay and co-benefits in depth. In 2023, Yang et al., taking Xuzhou as an example, investigated the specific impact of urban vibrancy across different dimensions on urban carbon emissions [34]. The research findings revealed that among the many influencing factors, the explanatory power of facility agglomeration on carbon emissions is relatively weak, while the explanatory power of the Normalized Difference Vegetation Index (NDVI) is the strongest. This discovery provides a valuable reference for constructing low-carbon and high-vibrancy cities. The study focuses on transportation and environmental indicators, with less attention given to building functions, land use, and people's activities.

2.3. Strategies for Carbon Reduction and Urban Vibrancy

Recent planning practices highlight strategies for carbon reduction at multiple scales. (1) Building Level: A main strategy is to promote green and low-carbon buildings that involve sustainable building materials, full electrification, and better efficiency [35]. In addition, a comprehensive life cycle assessment can also improve building operations and maintenance. (2) Neighborhood Level: The main strategies include enhancing pedestrian and cycling infrastructure, such as bike lanes, community gardens, and public green spaces for improving vegetation cover and air quality [36]. (3) District Level: The focus is developing a low-carbon transportation network. Strategies include deploying electric bus fleets and bike-share systems and optimizing the district energy supply with regional heating and cooling systems to improve energy efficiency [37]. (4) Urban Level: Urban planning incorporates Transit-Oriented Development (TOD), which promotes high-density development around public transportation hubs. There is also a push to strengthen the urban public transportation system by expanding its coverage and increasing service frequency [38]. (5) Regional Level: Efforts aim at carbon reduction in intercity transportation by promoting commuter rails and high-speed rails, along with renewable energy, including wind farms and solar power [39].

Despite the crucial impact of carbon emission reduction, it is not the singular goal for successful urban development. Strategies to enhance urban vibrancy across spatial scales are as follows: (1) Building Level: A primary strategy is to prioritize energy efficiency, sustainability, and the creation of social spaces such as public art installations and cafes. These initiatives aim to foster interaction and improve comfort levels through the integration of smart technologies [40]. (2) Neighborhood Level: The main strategy involves nurturing mixed-use development that blends live, work, and recreational areas. This approach is designed to enhance walkability and encourage community engagement through the organization of local events [41–43]. (3) District Level: The focus here is on revitalizing public spaces and establishing distinctive, lively neighborhoods and markets. These efforts are intended to attract a diverse array of visitors and enrich the overall urban experience [44]. (4) Urban Level: Urban planning strategies ensure diversity and inclusiveness, leveraging city branding to highlight iconic architecture and cultural events. This approach is aimed at elevating the city's global appeal [45]. (5) Regional Level: Efforts are concentrated on inter-city collaboration to optimize resource allocation and develop efficient transportation networks. This strategy is crucial for enhancing regional connectivity and boosting economic vibrancy [46]. In summary, cities also seek higher productivity, enriching innovations, economic prosperity, and well-being while pursuing sustainable growth. Therefore, it is necessary to analyze the relationship between urban carbon emissions and vibrancy and explore potential development strategies based on various conditions.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 May 2024 doi:10.20944/preprints202405.1585.v1

3. Data and Methods

3.1. Study area

This study selects Beijing's urban area within the Fifth Ring Roads as the study area, which has a dense population and a high degree of urbanization. the Fifth Ring Road transcends its role as a mere traffic conduit, embodying a temporal and spatial demarcation that delineates the city's evolution. It is a spatial boundary that partitions the city into the inner urban area and the sprawling suburbs, representing urban growth before and after the 21st Century. Thus, the study area represents the most urbanized area concentrated on political, economic, cultural, and social life, with the majority of housing, commercial centers, institutions, and public facilities. In addition, the study area is a testament to Beijing's diverse urban development, showcasing a unique blend of world-renowned historical areas, commercial centers, central business districts (CBD), and large-scale residential compounds. While brimming with vibrant urban activities, the study area also grapples with various challenges, particularly regarding environmental sustainability and livability. The rapid economic growth and accelerated urbanization have led to the escalation of environmental issues such as air quality, energy consumption, and carbon emissions, making the pursuit of a balance between urban development, sustainability, and livability a pressing concern in urban planning and management.

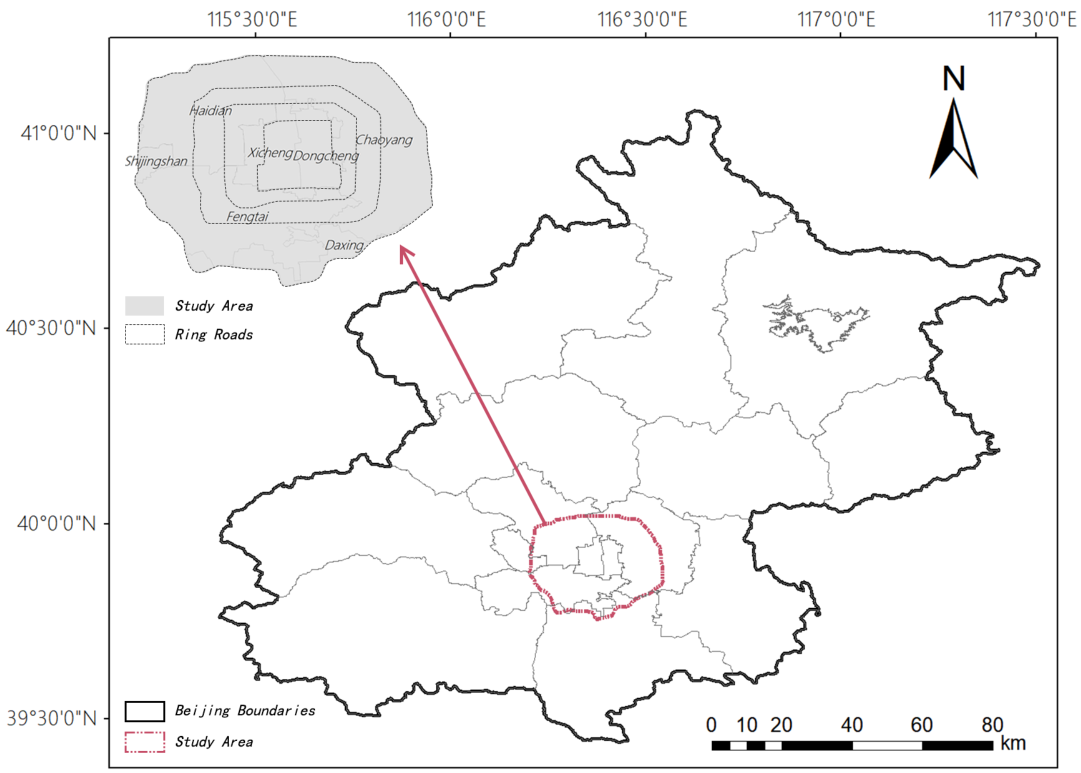

Figure 1. The study area within the Fifth Ring Road of Beijing.

3.2. Data Sources

In responding to the above challenges, this study aims to analyze the underlying relationship between local urban vibrancy and carbon emissions, hoping to identify co-benefits of urban vibrancy and low-carbon initiatives. By analyzing carbon emission patterns and the driving factors in different functional areas, our study seeks to outline strategies that simultaneously reduce emissions and

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 May 2024 doi:10.20944/preprints202405.1585.v1

enhance urban vitality. Ultimately, such findings may guide Beijing and other cities in achieving sustainable development by reducing carbon while promoting vibrant urban life. (Figure 1).

This study integrates multiple datasets from various sources. We utilize Beijing building data, administrative division data and road network data from OpenStreetMap (OSM) to form the basic dataset. By utilizing OSM's comprehensive and open-source geographic information base, we obtain detailed attributes of buildings, administrative divisions, and extensive road network information, which provides a foundation for subsequent computation and analysis. The land use data derived from EULUC-China, a comprehensive dataset integrates multi-source geospatial big data, including 10-meter resolution satellite imagery, OpenStreetMap(OSM), nighttime light data, Points of Interest (POI), and Tencent social big data, to classify and map urban land use types across China [47]. The dataset employs a two-level classification system adapted from the Chinese Standard of Land Use Classification known as Essential Urban Land Use Categories (EULUC). Training and validation samples were collected through a crowd-sourcing approach involving 21 research groups in 27 representative cities, ensuring the accuracy and reliability of the dataset.The dataset provides a comprehensive, high-resolution source for understanding urban land use patterns in China.

Table 1. Land use classification according to the EULUC-China dataset [47].

Primary Category	Secondary Category	Description
01 Residential Land	0101 Residential Land	Land primarily used for residential living quarters and their ancillary facilities.
02 Commercial and Service Land	0201 Commercial Office	Buildings where people work, including office buildings, trade, economy, IT, e-commerce, media, etc.
	0202 Trade Services	Land for commercial retail, catering, accommodation, and entertainment.
	0203 Other Services	Other commercial and service land uses.
	0204 Mixed-Use Areas	Areas that combine residential, commercial, and/or recreational uses.
	0205 Business Parks	Areas designated for businesses and light industrial activities.
03 Industrial Land	0301 Industrial Land	Land for production, storage, mining, and other industrial activities.
	0302 Mining Land	Land specifically for mineral resource extraction.
	0303 Other Industrial Land	Land for other industrial and production activities.
04 Transportation Land	0401 Road Pavement	Including highways, city roads, etc.
	0402 Transportation Stations	Transportation facilities including logistics, public transport, train stations, and ancillary facilities.
	0403 Airport Land	Land for civilian, military, or mixed-use airports.
05 Public Management and Service Land	0501 Government and Institutional Land	Land for government, military, public service institutions, and organizations.
	0502 Educational and Research Land	Land for education and research, including universities, schools, institutes, and ancillary facilities.
	0503 Medical Land	Land for hospitals, disease control, and emergency services.
	0504 Sports and Cultural Land	Land for public sports and training, cultural services, including sports centers, libraries, museums, and exhibition centers.
	0505 Parks and Green Spaces	Land for parks and green spaces used for recreation or environmental protection.

Regarding urban vibrancy, this study adopts a multi-dimensional urban vibrancy dataset released by a previous study in Beijing [48]. The vibrancy index derives from integrating high-resolution urban

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 May 2024 doi:10.20944/preprints202405.1585.v1

open data, Points of Interest (PoIs) obtained through API requests, and leisure running trajectories derived from data mining techniques. Creating the vibrancy index involves a multi-step computational, quantification, and modeling process designed to extract meaningful patterns from diverse urban data resources and analyze the relationship between vibrancy metrics and physical activity. The vibrancy data uses a high-resolution grid system that divides urban space into 1 km x 1 km grid cells. This division method allows researchers to analyze urban vitality and residents' activities in depth at the micro level. Thanks to this high-resolution approach, we can capture and analyze small changes and unique features in the urban fabric.

Table 2. Data Collection

Name	Spatial Unit	Sample Size	Source	Data Acquisition
Building Data	Polygon	297211	OpenStreetMap	API request
Administrative Boundary	Polygon	16	OpenStreetMap	API request
Street Network	Polyline	6037	OpenStreetMap	API request
Land Use	Polygon	440798	EULUC-China Dataset	Download
Population	Grid Cell(1km)	9251	Vibrancy Data	Download
Vibrancy	Grid Cell(1km)	9251	Vibrancy Data	Download

3.3. Carbon Emission Estimation

This study estimates building-level carbon emissions based on total built area and building types. Beijing issued a local standard for energy consumption indicators of civil buildings in 2017 [49]. This standard categorizes residential buildings into four groups based on building height (i.e., 1-3-storey low-rise, 4-8-storey multi-storey, 9-13-storey medium-high-rise, 14-storey and above high-rise) and estimates the average annual carbon emissions per square meter are 13.3, 11.6, 11.2, and 10.9, respectively (kgce/m2·a). For public buildings, carbon emission estimation varies by seven categories, including business office, commercial service, industrial, management, educational, medical, and cultural & sports, with estimated average annual carbon emissions per square meter of 20.1, 34.1, 46.6, 23.3, 16.8, 34.4, and 23.3 (kgce/m2·a), respectively. For building types with no specified emission parameters, such as management buildings and cultural and sports buildings, we use the average energy consumption per unit building area of public institutions in Beijing in 2020 as a substitute, with a specific value of 23.3(kg/m2·a). Due to the higher emission intensity, the carbon emission parameter of industrial buildings is approximately twice the average value [50].

We integrate parcel-level building data through spatial correlation to ascertain the floor area for each land use unit. Identifying whether the centroid of each building falls within a specific land use unit, we associate individual buildings with their corresponding units. When a building's centroid is confirmed to be within the boundaries of a particular land use unit, we categorize the building accordingly. We then calculate the total floor area within each land use unit. We incorporate population data and vibrancy indices from the vibrancy dataset. Employing spatial linkage techniques, we integrate the 1km x 1km grid-based vibrancy data with the carbon emission data at the land use unit level. By evaluating the location of grid cell centroids, we link these grid cells to their respective land use units. We calculate the total population for each land use unit and the average vibrancy index across all related grid cells to obtain representative vibrancy indicators. This approach allows for a nuanced understanding of the vibrancy within each land use unit. For calculating the total carbon emissions per parcel, the buildings are first categorized by land use, and the building area was multiplied by the corresponding energy consumption coefficient (Equation 1):

$$E_{\text{total}} = \sum (A \times S_{\text{building type}}) \tag{1}$$

where E_{total} represents the total carbon emissions (kgce/year), A is the building area (square meters), and $S_{\text{building type}}$ is the carbon emission coefficient for the respective building type (kgce/square

 doi:10.20944/preprints202405.1585.v1

meter·year). The parcel-level total emission is the sum of all building emissions, and carbon emission intensity represents emission per capita as total emission divided by local total population (Equation 2):

$$I_{\text{population}} = \frac{E_{\text{total}}}{P} \tag{2}$$

where $I_{\text{population}}$ is the per capita carbon emission intensity (kgce/year·person), and P is the population total of the respective land plot.

In order to analyze the relationship between carbon emissions and urban vibrancy, we first address potential biases caused by outliers in carbon emission intensity data. To mitigate this, we keep data within the 99th percentile to ensure our analysis focuses on a representative range of values. Our analysis proceeds in a two-step framework, initially examining the entire study area, followed by a detailed segmentation into residential and non-residential zones for a more nuanced evaluation. We estimate local vibrancy based on six indicators, including total population, percentage of residential, physical activity, business establishments, public facilities, and public space quality. The aggregate index is the cumulative sum of these six indicators, comprehensively measuring the area's vibrancy. The distribution of carbon emission intensity and vibrancy categorizes all land parcels into four groups using the third quantile (Q3) as the threshold: (1) high vibrancy with high carbon emissions; (2) high vibrancy with low carbon emissions; (3) low vibrancy with low carbon emissions; and (4) low vibrancy with high carbon emissions.

4. Results

4.1. Spatial Pattern of Carbon Emissions

The initial carbon emission estimation results show that the land parcel size directly affects the total carbon emissions, which aligns with common sense. As Figure 2 shows, university campuses and railway stations have high total carbon emissions due to the large plot sizes. While the estimated total carbon emissions are valuable, analyzing carbon emission intensity based on emissions per capita is also necessary. Previous studies consider that reducing carbon emission intensity is helpful to improve efficiency while reducing carbon footprint is helpful to reduce the total amount of greenhouse gas emissions related to individuals, organizations, or products [51]. A linear OLS model indicates that carbon emission intensity is positively related to the distance to the urban center (R-squared value=0.563, p-values<0.0001). As Figure 2 shows that carbon emission intensity gradually increases from the city center outwards, consistent with the spatial trend of increasing living area per capita from the urban center to its periphery. The overall carbon emission intensity within the Second Ring Road is relatively low, with multiple large-scale public buildings as outliers, including the National Museum and Center for the Performing Arts. Between the second and the third ring roads, financial districts, central business districts, large shopping centers, and sports facilities have the highest carbon emission intensity. Most areas with higher carbon emissions are between the Third and Fifth Ring Roads, including railway stations, the art district, and the Olympic Park.

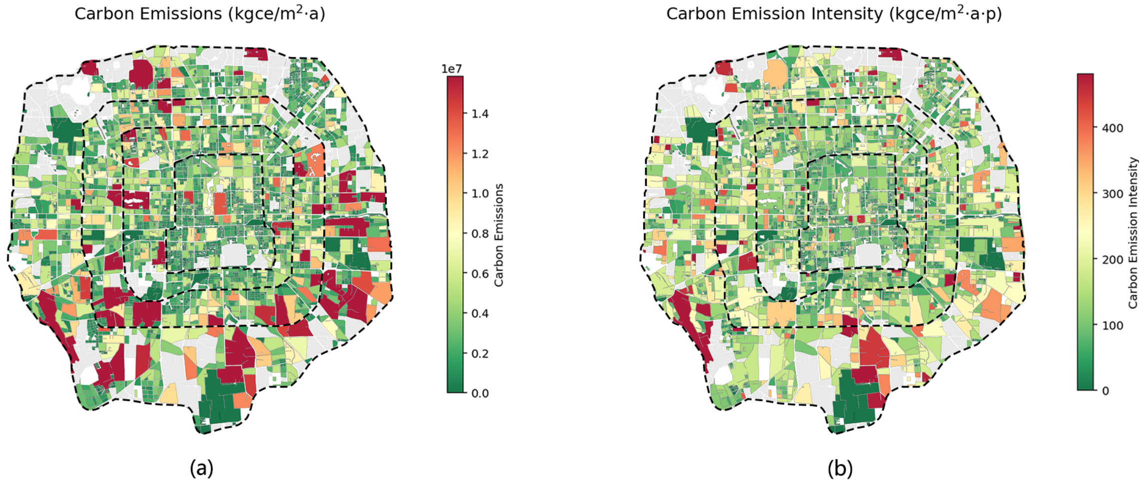

Figure 2. Estimated carbon emissions(a) and carbon emissions density(b) in Beijing.

The spatial autocorrelation analysis shows a certain degree of positive spatial autocorrelation in emission intensity (Moran's Index = 0.09), indicating a spatial cluster effect in carbon emission intensity. Figure 3 visualizes the clusters with high (in color red) and low (in color blue) carbon emission intensity based on spatial autocorrelation, indicating the connected areas with low or high carbon intensity within the city. This finding reveals the spatial distribution characteristics of carbon emissions and urban functions in Beijing, providing valuable references to support spatial strategies for emission reduction and future development. Despite the statistical significance, the clustering tendency is not strong due to the relatively low Moran's Index value. A more detailed cross-check with land use function shows that land parcels with higher per capita carbon emissions are mostly located in areas with public buildings such as medical, sports, cultural, commercial, and office buildings.

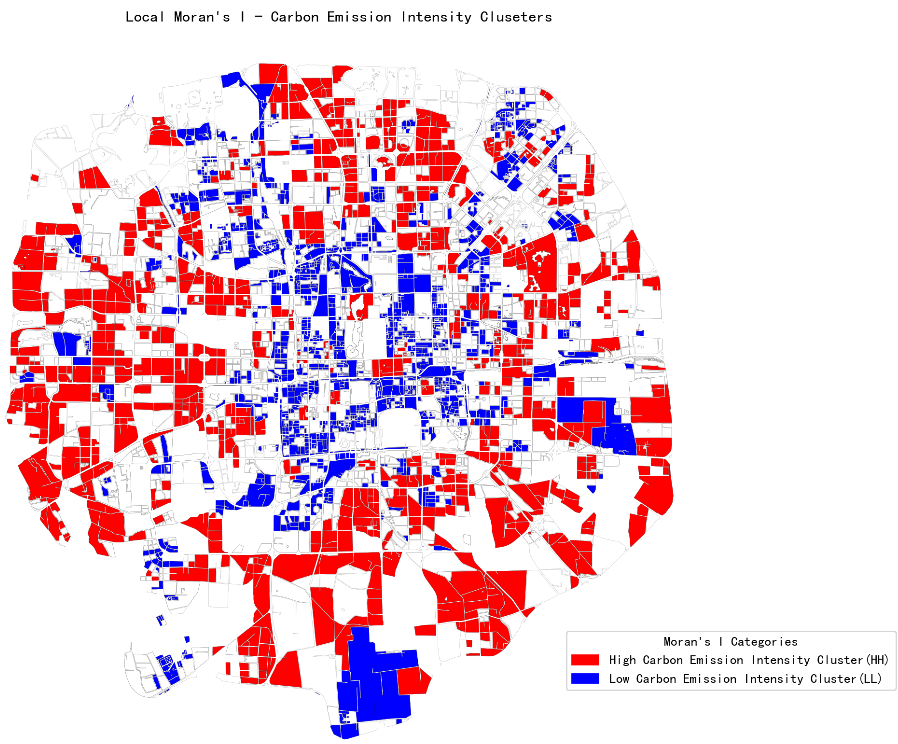

Figure 3. Spatial autocorrelation of carbon emission intensity according to Moran's I.

4.2. Relationship between carbon emission and urban vibrancy

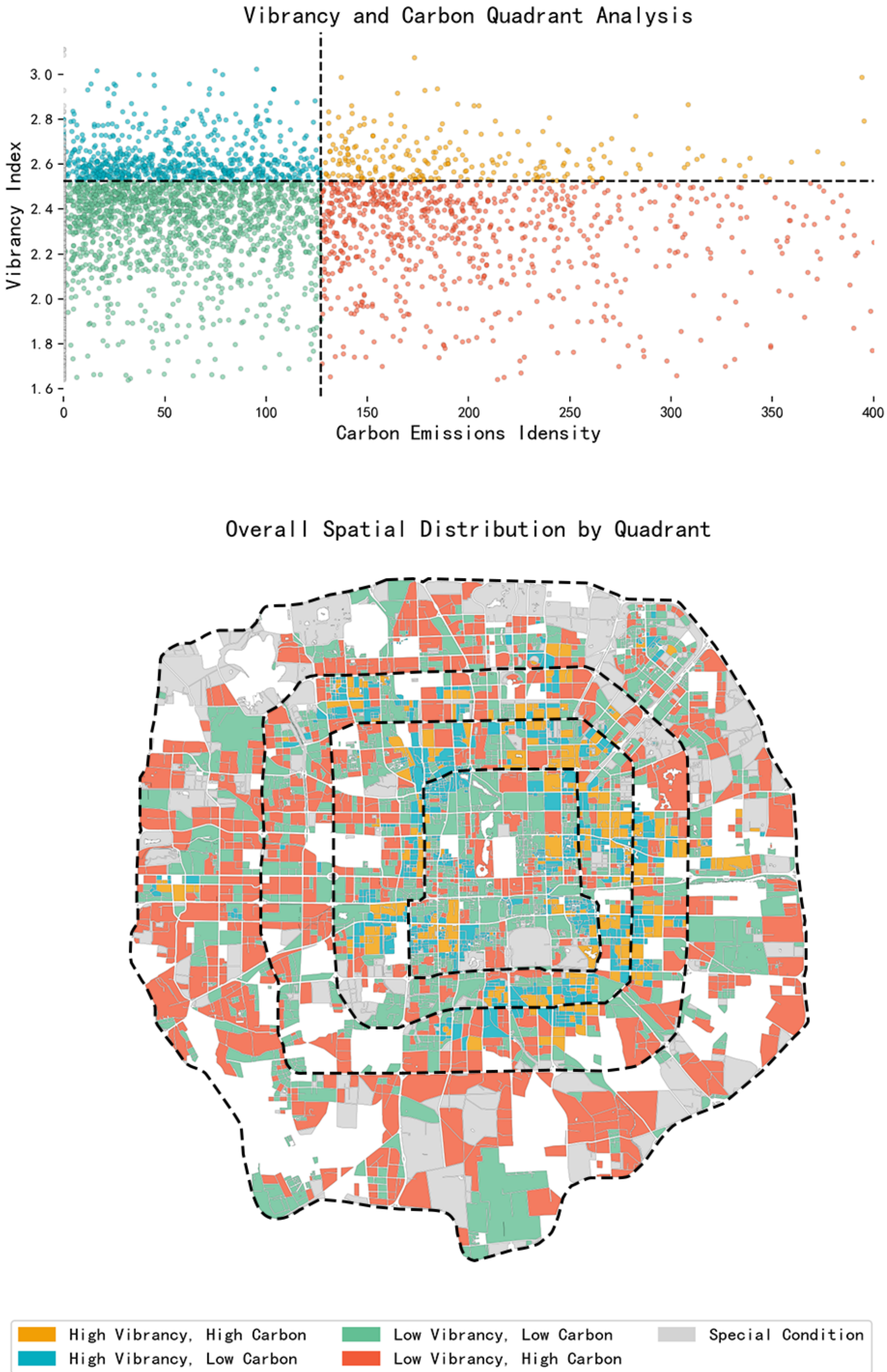

Figure 4. Spatial distribution of carbon emission and vibrancy combination typologies in Beijing.

This study uses a quadrant system to explore the combination and relationships between carbon emission intensity and urban vibrancy (Figure 4). The plots are categorized into four groups: high-carbon-high-vibration areas, high-carbon-low-vibration areas, low-carbon-high-vibration areas, and low-carbon-low-vibration areas. Overall, the spatial distribution of high-carbon-high-vibration and low-carbon-high-vibration areas exhibits a continuous and compact characteristic. These two areas interpenetrate each other spatially without showing significant distribution differences or regularities.

 doi:10.20944/preprints202405.1585.v1

Such areas are mainly concentrated within the Fourth Ring Road and relatively less distributed on the west side of the city. Specifically, the main concentration includes (1) commercial centers, such as Central Business District (CBD) and Taikoo Li Sanlitun, as hotspots for commercial activities and manifestations of urban vibrancy. (2) High-density urban living blocks, usually composed of public institutions, residential areas, and schools, such as the living blocks around the Financial Business District and the south side of the Temple of Heaven Park; (3) High-tech industrial parks, such as Zhongguancun Science Park, which is an important base for scientific and technological innovation and research and development activities. Urban areas with lower vibrancy broadly disperse throughout the city, with a discernible shift from low-carbon, low-vibration areas towards those with high-carbon, low-vibration areas as one ventures from the city's core to its outskirts. This observed trend aligns closely with the distribution pattern of per capita carbon emission intensity.

4.3. Differences between residential and non-residential areas

Linear OLS models between local vibrancy and carbon emission intensity show that these two factors have different relationships in residential and non-residential areas. While results indicate a significant relationship between two factors in general ($p-$values < 0.0001), local vibrancy has a higher predicting power in residential areas (R-squared value=0.573) than those in non-residential areas (R-squared value=0.379). The analysis further compared residential and non-residential areas by delving into the interplay and combination distribution of carbon emission intensity and urban vibrancy across different types of land use. The results reveal two main spatial patterns in residential areas. First, Beijing's inner city area within the Second Ring Road predominantly demonstrates low carbon and low vibrancy characteristics. Meanwhile, all four types of areas are present for urban areas between the Second and Fourth Ring Roads, indicating a more complex spatial characteristic. The areas between the Fourth and Fifth Ring Roads are mainly high carbon-low vibrancy and low carbon-low vibrancy types.

Regarding the distribution of each category, high carbon-high vibrancy areas are mainly concentrated between the Second and Fourth Ring Roads, with a notable scarcity in the western areas, except for Beijing West Station and several communities in its southern part. Low carbon-high vibrancy areas are generally located within the Third Ring Road, while high carbon-low vibrancy areas are mostly distributed outside the Third Ring Road. In contrast, the distribution of low carbon-low vibrancy areas appears more uniform. Such results show the spatial pattern in which the per capita carbon emission intensity gradually increases from the city center to the outside while vibrancy gradually decreases. These results show that the spatial pattern of carbon emission intensity gradually increases from the city center to the outside, and the urban living vibrancy gradually decreases from the city center to the outside. Meanwhile, the living vibrancy of the east side of Beijing is better than that of the west side.

The results show a mixture of four types of non-residential areas within the study area, indicating a much more complex spatial distribution between local carbon intensity and urban vibrancy (Figure 5). University campuses and education institutions, large financial districts, and sports stadiums are common places with high carbon intensity and high vibrancy. High-carbon, low-vibration areas are primarily distributed between the Third and Fifth Ring Roads, with these areas generally having larger land plots. The number of low-carbon, high-vibration areas is small and dispersed in distribution. Low-carbon, low-vibration areas are mainly located within the Third Ring Road and also partially distributed between the Third and Fifth Ring Roads. Generally speaking, the vibrancy of non-residential land in the north of Beijing is slightly higher than in the south. In summary, the findings above indicate that the integrated classification method, which combines carbon emission intensity with urban vibrancy, has a more pronounced impact on residential land. Specifically, the four combinations exhibit a more orderly distribution across residential land rather than being intermixed. Such findings suggest that the interplay between carbon emission intensity and urban vibrancy may significantly influence residential areas' spatial organization and planning.

 doi:10.20944/preprints202405.1585.v1

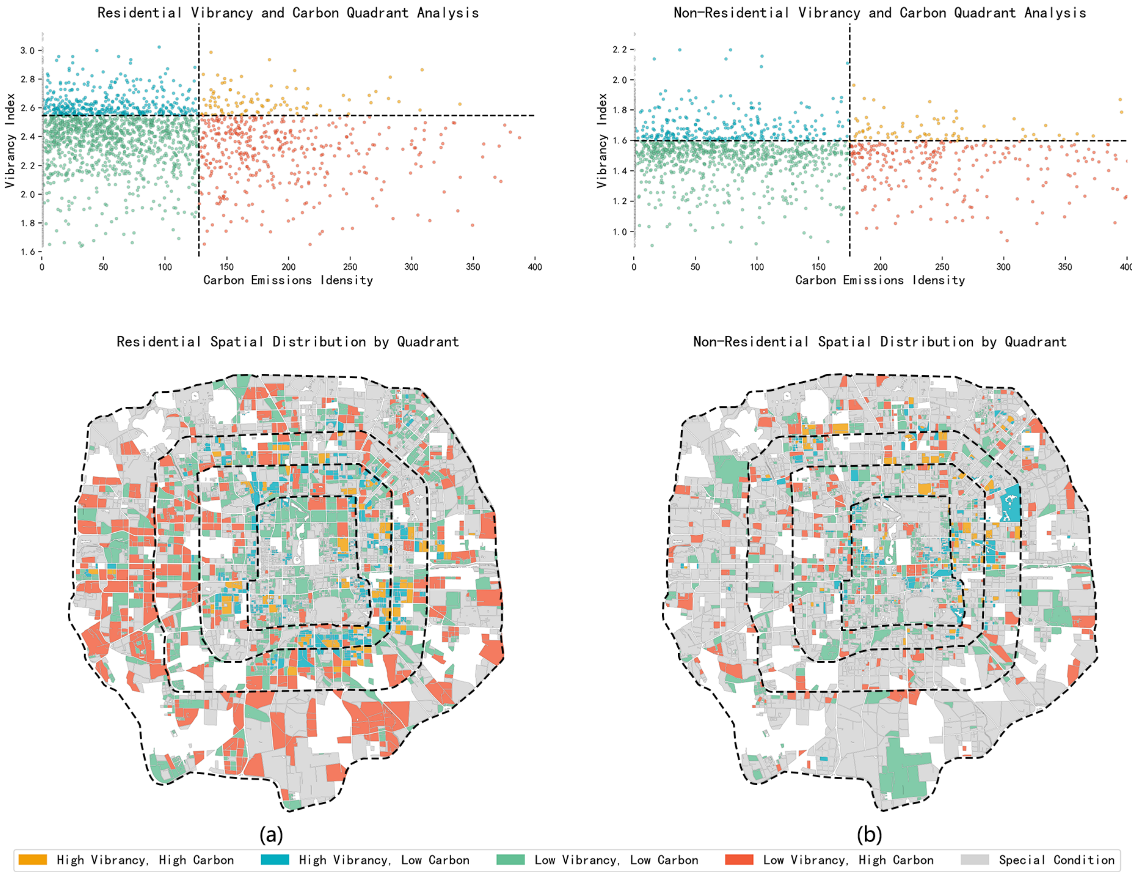

Figure 5. Spatial distribution of carbon emission intensity and vibrancy combination typologies in residential(a) and non-residential(b) areas.

5. Discussion

This study explores an integrated classification method combining carbon emission intensity and urban vibrancy on residential land. Our findings may shed light on the future planning and development strategies for different combinations in residential areas. From the perspective of universal values, low carbon, and high vibrancy should become the core objectives of future urban development, but they may be different in some cases. Against the backdrop of the dual carbon targets, low-carbon development has become a global consensus and should also be the common goal pursued by all urban areas. Increasing the living area per capita and reducing residential density can enhance residents' quality of life and lower total carbon emissions. However, this may also lead to a proportional increase in carbon emission intensity from residential areas. As Chinese cities transition to high-quality and more human-oriented development, such trade-offs become more pronounced with cities formulating strategies that could significantly shape the future of urban vibrancy development. Considering the significant impact of the integrated classification method combining carbon emission intensity and urban vibrancy on residential land, this study may support more targeted guidance and suggestions for future planning and development strategies based on different carbon-vibrancy combinations.

These results indicate that planning decisions should assess urban vibrancy based on specific indicators rather than solely relying on the overall index of residential vitality. For Beijing, our study provides insights into future urban planning in the unique context of its long-term development strategy with local policies. In July 2015, the Beijing Municipal Development and Reform Commission identified non-core functions and their relief solutions [52]. With that, the Beijing Urban Master Plan (2016-2035) introduced the innovative concept of "reduced development" for the first time, aiming to optimize the functions of the capital city by improving public service quality and enhancing its competitiveness among global cities [53]. Since implementing these policies, the related planning actions have made remarkable changes in population, reducing the permanent residents from 12.828 million to 10.985 million, with almost 2 million population reduction within the urban core area only within five years (2015 to 2020) [54]. The policies and practices outlined suggest that the local population in Beijing's central area may continue to decline, potentially leading to decreased urban vibrancy. Nevertheless, urban construction will continue to provide high-quality human settlement services and commercial activities in the future to enhance residential vibrancy [55]. Given the complexity of urban dynamics and the complex nature of urban vibrancy, a multidimensional analysis is essential for proposing planning strategies. This includes, but is not limited to, population trends, service infrastructure, commercial activities, and experiential products available to residents.

We outline the following planning strategies for future development regarding the local carbon-vibrancy combinations(Figure **??**). The high-carbon, high-vibrancy urban areas predominantly represent high-energy-consuming public facilities, such as major transportation hubs and commercial centers. These residential areas provide relatively spacious per capita living space with comprehensive peripheral service facilities, offering superior living conditions yet with relatively high energy consumption. Thus, future development strategy should focus on energy conservation by integrating housing, transportation hubs, commercial facilities, and office spaces into an interconnected and intelligent energy system. Such an approach allows real-time monitoring and displaying of energy consumption by peak-hour energy management across various buildings with power distribution efficiency improvement [56]. This innovative energy management strategy has the potential to sustain the city's vibrancy and provides an efficient solution for reducing carbon emissions.

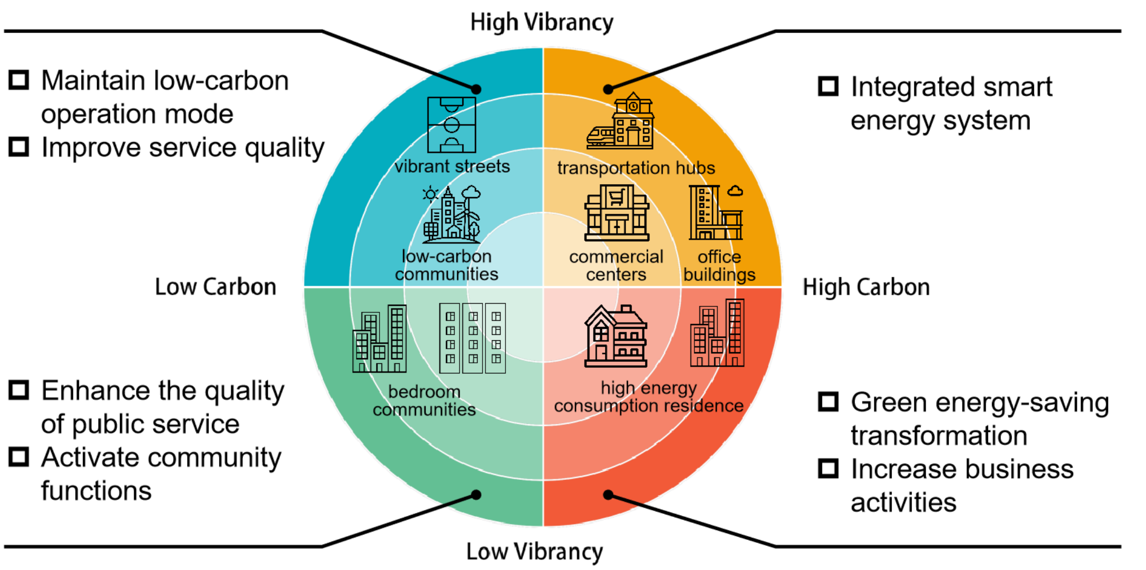

Figure 6. Development strategies for different carbon-vibrancy combinations.

For high carbon-low vibrancy urban areas, they are relatively spacious with comparatively favorable living conditions, including higher building energy consumption but a shortage in facility provision. Future urban planning and architectural design can respond to this problem through two strategies. Firstly, green energy-saving retrofits can enhance existing residential buildings by integrating solar energy utilization technologies [57,58] and the recovery of biomass energy from community waste for sustainable energy use [59]. Secondly, increasing the density of facilities and invigorating commercial activities can enhance the quality of life for residents. Specific measures include the construction of smart blocks that integrate commercial and residential functions [60], as well as the lead-in of mobile intelligent service facilities within residential areas [61]. These initiatives aim to bolster the community's vibrancy and attractiveness by improving the accessibility and convenience of service facilities.

For low carbon-high vibrancy urban areas, they exhibit a robust developmental trajectory with high living quality and service standards. It is imperative for these areas to continue employing low-carbon operational models while maintaining a high standard of service quality. The city may transform these areas into exemplary districts of low-carbon and high vibrancy to sustain and enhance local capacity for sustainable development. This transformation will involve introducing innovative technologies and management practices to achieve dual improvements in environmentally friendly development and the quality of life for residents.

Low carbon-low vibrancy urban areas have deficiencies in the living environment and supporting service facilities despite relatively low carbon emissions. In light of the potential for a further decrease in population density, these areas should focus on enhancing the quality of public services and living conditions. Innovative transformation and functional activation of street spaces can effectively augment the vibrancy and appeal of the community. The second segment lies between the Fourth and Fifth Ring Roads, where residential communities exhibit a high population density but lack overall vibrancy, often being perceived as "bedroom communities" [62]. For local vibrancy estimation, it is conceivable to re-purpose some of the currently underutilized residences into multi-functional service facilities or commercial outlets or convert them into flexible public activity spaces. Such a transformation would elevate the community's level of service and foster the development of the community's economy, thereby enhancing the quality of life for residents and the overall vibrancy.

Overall, this study analyzes the interplay between urban vibrancy and carbon emissions in residential and non-residential areas in Beijing. The findings reveal urban development patterns under different combination typologies and propose targeted planning strategies accordingly. These strategies aim to promote the construction of key areas such as low-carbon vibrancy demonstration zones, smart energy networks, vibrant streets, and green low-carbon buildings, providing a reference for the sustainable development of future communities. We acknowledge the limitations in carbon emission estimation, primarily due to the timeliness and public availability of data. To obtain more accurate carbon emission data, it is suggested that future urban development should enhance the measurement and disclosure of building energy consumption information to gain a grasp on the actual carbon emission situation. This approach to improvement has been validated in practice in international metropolises such as New York [63]. Based on this study, future research can further explore the various factors influencing the spatial distribution of combination typologies in cities and develop more precise adjustment strategies to achieve the dual goals of urban vibrancy and low-carbon development. Additionally, the methodology and discoveries of this study also have the potential to be extended to other cities and to further analyze key urban issues such as urban population distribution, construction density, and urban heat island effects. Through these efforts, a scientific basis and practical guidance can be provided for constructing a more sustainable, efficient, and environmentally friendly urban living environment.

6. Conclusions

In conclusion, this study explores the intricate nexus between urban carbon emissions and urban vibrancy. The research findings reveal the particularly pronounced effectiveness of the four-quadrant analysis method in categorizing residential land use. Based on the spatial patterns of urban carbon-vibrancy combinations, this paper proposes corresponding strategies for future development drawing from key fields such as integrated smart energy systems, low-carbon vibrancy priority zones, vibrant residential streets, and green low-carbon architecture. For instance, areas within Beijing's city center, characterized by high carbon emissions and vibrancy, necessitate implementing intelligent energy-saving strategies and establishing an interconnected smart energy system. In contrast, well-developed urban areas with low carbon emissions but high vibrancy should adopt low-carbon operational models to serve as exemplary areas for sustainable living. In the long run, this method supports policy formulation and planning practices to promote sustainable urban development and balance carbon emission reduction and enhanced vibrancy.

Author Contributions:

Funding:

Conflicts of Interest:

References

1. Yang, Y.;Li, G.P.;Sun, Y. et al. Comparative Study on Urban Physical Examination and Planning Implementation Evaluation of Big Cities at Home and Abroad. *Scientia Geographica Sinica* **2022**, *42*, 198-207.
2. Guo, X.D.; Jiang, J.S.; Jia, Z. et al. Discussion on urban renewal path under the background of new urbanization.Planning for 60 Years: Achievements and Challenges —— Proceedings of 2016 China Urban Planning Annual Conference (08 Urban Culture) , Shenyang, China **2016**, 1330-1337.
3. UN HABITAT. World Cities Report 2022.**2022**,https://unhabitat.org/wcr/
4. Intergovernmental Panel on Climate Change. Climate Change 2001: Impacts, Adaptation, and Vulnerability. IPCC Third Assessment Report.**2001**, Cambridge University Press, Cambridge, UK.
5. Intergovernmental Panel on Climate Change. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.**2001**,Cambridge University Press, Cambridge, UK.
6. Qian, X.S. Systems Science, Thinking Science and Somatic Science. *Chinese Journal of Nature* **1981**, *1*, 3-9.
7. Wu, L.Y. *Introduction to Sciences of Human Settlements*;Beijing: China Architecture & Building Press, 2001.
8. Lai, Y.; Zheng, X.J.; Xia, J.Y.Theory of Intelligent Human Settlements and Technical Planning Principles from the Perspective of Urban System. *Urban Planning* **2023**, *47*, 89-96.
9. Abeydeera, L.H.U.W.; Mesthrige, J.W; Samarasinghalage, T.I. Global Research on Carbon Emissions: A Scientometric Review. *Sustainability* **2019**, *11*, 3927.
10. Wang, Y.Z.; Wang, X.P.; Chen, Q.Y. Review of Research on Urban Carbon Emission Measurement Methods and its Implications. *City Planning Review*. **2024**. https://link.cnki.net/urlid/11.2378.TU.20240124.1837.004.
11. Andres, R.J.; Marland, G.; Fung, I. et al. A 1 degrees x1 degrees distribution of carbon dioxide emissions from fossil fuel consumption and cement manufacture, 1950-1990. *Global Biogeochemical Cycles* **1996**, *10*, 419-429.
12. Van Vuuren, D.P.;Hoogwijk, M.; Barker, T.Comparison of top-down and bottom-up estimates of sectoral and regional greenhouse gas emission reduction potentials. *Energy Policy* **2009**, *37*, 5125-5139.
13. Lee, S.; Lee, B. The influence of urban form on GHG emissions in the US household sector. *Energy policy* **2014**, *68*, 534-549.
14. Huo, T.F.;Li, X.H.;Cai, W.G. et al. Exploring the impact of urbanization on urban building carbon emissions in China: Evidence from a provincial panel data model. *Sustainable cities and society* **2020**, *56*, 102068.
15. Wang, T.T.;Shen, B.;Springer, C.H. et al. What prevents us from taking low-carbon actions? A comprehensive review of influencing factors affecting low-carbon behaviors. *Energy research & social science* **2021**, *71*, 101844.
16. Yamagata, Y.; Yoshida, T.;Murakami, D. et al. Seasonal Urban Carbon Emission Estimation Using Spatial Micro Big Data. *Sustainability* **2019**, *10*, 4472.
17. Carta, S.; Pintacuda, L.; Turchi, T. et al. CINT City Net-Zero Tool: A Method to Quantitatively Assess Carbon Data in Urban Areas. *2023 IEEE International Symposium on Technology and Society (ISTAS)*, Swansea, UK **2024**, 1-6.
18. Jacobs, J. In *The Death and Life of Great American Cities.*; Publishing House: New York, America, 1961.
19. Huang, B.; Zhou, Y.L.; Li, Z.G. et al. Evaluating and characterizing urban vibrancy using spatial big data: Shanghai as a case study. *Environment and Planning B: Urban Analytics and City Science* **2020**, *47*, 1543 - 1559.
20. Tu, W.; Zhu, T.T.; Xia, J.Z. et al. Portraying the spatial dynamics of urban vibrancy using multisource urban big data. *Computers, Environment and Urban Systems* **2020**, *80*, 101428.
21. Zhang, Y.F.; Zhong, W.J.; Wang, D. et al. Understanding the spatiotemporal patterns of nighttime urban vibrancy in central Shanghai inferred from mobile phone data. *Regional Sustainability* **2021**, *2*, 297-307.
22. Zhu, T.T.; Tu, W.; Yue, Y. et al. Sensing urban Vibrancy using geo-tagged data. *Acta Geodetica et Cartographica Sinica* **2020**, *49*, 365-374.

23. Wang, X.X;Zhang, Y.J.;Yu, D.L. et al. Investigating the spatiotemporal pattern of urban vibrancy and its determinants: Spatial big data analyses in Beijing, China. *Land Use Policy* **2022**, *19*, 106162.
24. Lu, S.W.;Shi, C.Y.;Yang, X.P. et al. Impacts of Built Environment on Urban Vitality: Regression Analyses of Beijing and Chengdu, China. *International Journal of Environmental Research and Pubilc Health.* **2019**, *16*, 4592.
25. Gao, C.;Li, S.S.;Sun, M.P. et al. Exploring the Relationship between Urban Vibrancy and Built Environment Using Multi-Source Data: Case Study in Munich. *Remote Sensing.* **2024**, *16*, 1107.
26. Liu, D.; Shi, Y. The Influence Mechanism of Urban Spatial Structure on Urban Vitality Based on Geographic Big Data: A Case Study in Downtown Shanghai. *Buildings.* **2022**, *12*, 569.
27. Zhang, Z.; Zhang, Y.; He, T. et al. Urban Vitality and its Influencing Factors: Comparative Analysis Based on Taxi Trajectory Data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing.* **2022**, *15*, 5102-5114.
28. Zikirya, B.; He, X.; Li, M. et al. Urban food takeaway vitality: A new technique to assess urban vitality. *International Journal of Environmental Research and Public Health.* **2021**, *13*, 3578.
29. Barreca, A.;Curto, R.;Rolando, D. Urban Vibrancy: An Emerging Factor that Spatially Influences the Real Estate Market. *Sustainability.* **2020**, *12*, 346.
30. Lu, R.J.; Wu, L.; Chu, D.P. Portraying the Influence Factor of Urban Vibrancy at Street Level Using Multisource Urban Data. *Isprs International Journal of Geo-Information.* **2023**, *12*, 402.
31. Meng, Y.;Xing, H.F. Exploring the relationship between landscape characteristics and urban vibrancy: A case study using morphology and review data. *Cities.* **2019**, *95*, 102389.
32. Ouyang, J.N.; Fan, H; Wang, L.Y.et al. Revealing urban vibrancy stability based on human activity time-series. *Sustainable Cities and Society.* **2022**, *85*, 104053.
33. Li, X.; Li, Y.; Jia, T. et al. The six dimensions of built environment on urban vitality: Fusion evidence from multi-source data. *Cities.* **2022**, *121*, 103482.
34. Yang, H.;He, Q.P.;Cui, L. et al. Exploring the Spatial Relationship between Urban Vitality and Urban Carbon Emissions. *Remote Sensing.* **2023**, *15*, 2173.
35. Zhang, Y.F. Research on Low-carbon Architectural Development Based on Green Life Cycle. *Computer-Aided Design, Manufacturing, Modeling and Simulation III* **2014**, *443*, 263-267.
36. National Development and Reform Commission. Guide to pilot construction of low-carbon communities. **2015**, https://www.ndrc.gov.cn/xxgk/zcfb/tz/201502/W020190905507344001670.pdf
37. Chen, Q.;Zhang, X.;Lin, J.G. et al. Construction Scheme of Future Community Low-carbon Scenarios. *Energy Research and Management.* **2021**, *2*, 18-22+53.
38. Liu,R.Y ; Feng, H.X.; Lu, H.P. et al. Mechanism Analysis and Calculation Method of Traffic Carbon Reduction Effect Based on TOD Mode. *Urban Studies.* **2022**, *29*, 56-62,99.
39. Beijing Jiaotong University Comprehensive Transportation Research Center. Research on the Optimization Strategy of Travel Structure of High-speed Railway and Civil Aviation under the Double-carbon Target. *Sustainable Energy, Prosperous Future.* **2023**, https://www.efchina.org/Reports-zh/report-ctp-20230725-zh-3
40. Hafez, F.S; Sa'di, B.; Safa-Gamal, M. et al. Energy Efficiency in Sustainable Buildings: A Systematic Review with Taxonomy, Challenges, Motivations, Methodological Aspects, Recommendations, and Pathways for Future Research. *Energy Strategy Reviews.* **2023**, *45*, 101013.
41. Geyer, H.S. The theory and praxis of mixed-use development - An integrative literature review. *Cities.* **2024**, *147*, 104774.
42. Barrie, H.; Mcdougall, K.; Miller, K. et al. The social value of public spaces in mixed-use high-rise buildings. *Buildings and Cities.* **2023**, *4*, 669-689.
43. Nautsch, A.H.Exploring Walkability: A Spatial Analysis of Vibrancy in New Holly, a New Urbanist Community in South Seattle, WA. *University of Washington.* **2017**, https://webofscience.clarivate.cn/wos/alldb/full-record/PQDT:61027677
44. Park, S. Vibrant Traditional Markets in Small Residential Neighborhoods; A Case Study of their Urban-Spatial Characteristics in Gwanak-gu District, Seoul. *Journal of the Architectural Institute of Korea Planning & Design.* **2017**, *33*, 73-83.
45. Yue, Y.; Zhuang, Y.; Yeh, AGO. et al. Measurements of POI-based mixed use and their relationships with neighbourhood vibrancy. *International Journal of Geographic Information Science.* **2017**, *31*, 658-675.
46. Katharine, A.R.; Michelle L.; Kathryn, H. et al. Inter-city collaboration: Why and how cities work, learn and advocate together. **2023**, https://doi.org/10.1111/1758-5899.13292

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 May 2024 doi:10.20944/preprints202405.1585.v1

47. Peng Cheng Laboratory. Essential Urban Land Use Categories in China (EULUC-China): preliminary results for 2018. **2020**, https://data-starcloud.pcl.ac.cn/zh/resource/7. Last updated 9/26/2023.
48. Lai, Y.;Li, J.T.;Zhang, J.C. et al. Do Vibrant Places Promote Active Living? Analyzing Local Vibrancy, Running Activity, and Real Estate Prices in Beijing. *International Journal of Environmental Research and Public Health.* **2022**, *19*, 16382.
49. Beijing Municipal Administration of Quality and Technology Supervision. The energy consumption index for civil buildings. **2017**, http://bzh.scjgj.beijing.gov.cn/bzh/apifile/file/2021/20210325/33864a98-7e3b-4874-b033-f3c1c09d5e24.PDF.
50. Beijing Municipal Administration of Government Logistics. Work Plan for Saving Energy and Resources of Public Institutions in Beijing during the Tenth Five-Year Plan Period. **2022**, https://jgj.beijing.gov.cn/zwgk/zcwj/202203/t20220323_2637620.html
51. EarthShift Global. Carbon Footprint vs. Carbon Intensity. **2024**, https://earthshiftglobal.com/blog/carbon-footprint-vs.-carbon-intensity
52. Du, L.Q.; He, C.D. Study on the Dispersal of Non-capital Functions in Beijing. *Shanghai Urban Planning Review.* **2015**, *6*, 17-20.
53. The People's Government of Beijing Municipality. Beijing Urban Master Plan (2016-2035).**2017**, https://www.beijing.gov.cn/gongkai/guihua/wngh/cqgh/201907/t20190701_100008.html
54. The People's Government of Beijing Municipality. Blue Book of Beijing Population: The quality of the population continues to improve, ranking among the top in the country.**2021**, https://www.beijing.gov.cn/ywdt/gzdt/202112/t20211212_2559212.html
55. Beijing News Review. From agglomeration to disintegration, Beijing releases incremental scenery with reduced development. **2022**, https://new.qq.com/rain/a/20220628A013AL00
56. Vardakas, J.S.; Zenginis, I.; Zorba,N. et al. Electrical energy savings through efficient cooperation of urban buildings: the smart community case of superblocks' in Barcelona. *IEEE Communications Magazine.* **2018**, *56*, 102-109.
57. Zhao, L.; Zhao, W.; Yao, H. et al. Research on Performance-Based Design of Residential Energy Saving Based on Solar Energy Utilization. *Industrial Construction.* **2023**, *53*, 57-64,157.
58. Yang, J.D.; li, Y.G. Research on the Application of Green Energy Saving Technology in Building Renovation. *Energy Conservation and Environmental Protection.* **2022**, *7*, 43-45.
59. Vázquez-Canteli, J.R.; Ulyanin, S.; Kämpf, J. et al. Fusing TensorFlow with building energy simulation for intelligent energy management in smart cities. *Sustainable cities and society.* **2019**, *45*, 243-257.
60. Park, J.W.; Choi, S. Urban Smart Block: An Open IoT Platform for Creating Online-to-Offline Services in Urban Environments. *International Journal of Embedded and Real-Time Communication Systems (Ijertcs).* **2019**, *10*, 21-31.
61. Woven City. TOYOTA Woven City.*Woven City Press.*, **2023**, https://www.woven-city.global/.
62. Zhang, B.B.; Liu, Y.G. Commuter Town's Problems, Transition and Future: A Case Study of Tama New Town, Japan. *Urban Planning International.* **2017**, *32*, 130-137.
63. Kontokosta, C.; Lai, Y.; Bonczak, B. et al. A Dynamic Spatial-Temporal Model of Urban Carbon Emissions for Data-Driven Climate Action by Cities. *Bloomberg Data for Good Exchange Conference.* , New York City, USA **2018**, https://par.nsf.gov/servlets/purl/10083415