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Implementation path of dual-carbon in Xiguan historical and cultural district of Guangzhou : A case study on changhua street

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ABSTRACT

In the context of ecological civilization construction, cities are the main source of greenhouse gas emissions and thus they are key areas for dual-carbon construction. The dual-carbon community is the basic unit of the dual-carbon city and is essential for the promotion and construction of beautiful China. Guangzhou, as a historical and cultural city, is actively exploring the micro-renewal path of historical and cultural neighborhoods. In this paper we explore the micro-renewal process of the dual-carbon community and the Guangzhou Xiguan historical and cultural district, as well as their mutual relationship. In particular, we take the historical and cultural district of Guangzhou Xiguan Changhua Street as an example and explore its carbon emission characteristics based on the Intergovernmental Panel on Climate Change (IPCC) inventory compilation method. The carbon emission of this community in 2022 was determined as 3774670 kg, indicating the characteristics of low carbon emissions per capita but high energy consumption. Changhua Street provides a dual-carbon micro-renewal strategy and suggests a dual-carbon implementation path for the Guangzhou Xiguan historical and cultural district in the micro-renewal process.

1. Introduction

With the rapid global development in recent decades, carbon emissions have increased dramatically [1,2]. In order to find a response to the severe status of climate change, the United Nations has reached the Paris Agreement, Transforming Our World: The 2030 Agenda for Sustainable Development, and the New Urban Agenda, among other frameworks. Moreover, at the 75th session of the United Nations General Assembly, China put forward the goals of achieving carbon peaking by 2030 and striving to achieve carbon neutrality by 2060 [3]. The shift from low-carbon to dual-carbon perspective highlights the dual enhancement of national construction goals and connotations.

Guangzhou has also been actively building a dual-carbon development path [4]. In 2012, Guangzhou was included in the second batch of national low-carbon regions and low-carbon city construction pilot areas announced by the National Development and Reform Commission (NDRC) of China. Guangzhou has implemented a series of reform measures around the dual-carbon goal, such as: issuing the *Implementation Plan for Low Carbon City Pilot Work in Guangzhou* in 2012, which elaborated the main work of low-carbon pilot construction. In 2022, Guangzhou City carried out the waste-free city pilot project, and proposed the corresponding construction mechanism and index system *Guangzhou "Waste-Free City" Pilot Implementation Plan (Draft for Comments)*. In addition to focusing on

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key areas of dual-carbon construction, Guangzhou has also taken the lead in building the CarbonWiset platform to quantify the energy saving and carbon re-duction behaviors of individuals, communities and even small and micro enterprises in their daily behavior, and to establish a certain incentive mechanism to form positive feedback.

Large cities are key emitters of the vast majority of greenhouse gases (GHG) [5], and communities are an important element in the composition of cities and an important vehicle for addressing global climate change [6,7]. Denmark, the UK, Germany and Sweden have taken the lead in exploring the practice of dual-carbon communities, such as: the Danish Sun & Wind Community [8], which emphasizes the voluntary construction of residents; the Beddington Community in the UK [9], which has built the world's first zero-energy community; the Forms of Citizen Participation introduced in Vauban District in Germany [10]; and the exploration of the transition from a polluted industrial port area to a sustainable community by Hammaby Sjöstad in Sweden [11]. In contrast, China's dual-carbon communities started late, and the current so-called low-carbon communities are mainly new city developments, such as the Asian Games City community in Guangzhou [12], the Sino-Swedish Low Carbon Eco-City in Wuxi [13], and the Sun Star City in Changsha, whose planning and construction models and management practices lack sound guidance.

Research in dual-carbon communities can be broadly categorized into the following three types. The first type is the exploration of carbon emission accounting methods. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories issued by the United Nations Intergovernmental Panel on Climate Change(IPCC) [14], the *Guidelines for the Preparation of Greenhouse Gas Inventories at the City, County (District) Levels of Guangdong Province* by the Department of Environment of Guangdong Province [15], China, hereinafter referred to as the *Guidelines*, and the Greenhouse Gas Accounting Tools for Chinese Cities(Pilot Version 1.0)issued by the World Resources Institute at the national, provincial and city level to guide carbon emission accounting. For community-level carbon accounting methods, Barthelmie et al. [16] developed a community carbon footprint model to assess the scale of community carbon emissions and the proportion of major emission activities. Jones et al. [17] used the Life Cycle Assessment to account for carbon emissions from the transport, energy, water and waste sectors within the study area. Zhan et al. [18] constructed a carbon accounting method to established urban communities based on the IPCC inventory development method. The second type is the development of a dual-carbon community evaluation index system. Countries have formed numerous comprehensive systems, such as the LEED-ND from the US Green Building Council, the BREEAM communities in the UK, and the CASBEE for Urban Development system in Japan [19]. China released the *Pilot Low Carbon Communities Construction Guide* in 2015, and several pilot regions have thus released their low carbon community evaluation index systems. For example, Guangdong Province declared the *Guangdong Province Low-Carbon Community Evaluation Index System* in 2017. Several scholars have also conducted research on the evaluation index system of low-carbon communities. Wang et al. [20] constructed a low-carbon community evaluation index system from the perspectives of carbon source control and carbon sinks expansion. Xie et al. [21] applied the SMART criteria to establish a low-carbon community evaluation system in Guangdong Province, while Bai et al. [22] applied the empirical analysis method and improved the AHP method to establish a low-carbon community evaluation system. The third is to explore the implementation path of the dual-carbon community. Moloney et al. [23] argued that creating a low-carbon community requires community households to become more aware of the concept of low-carbon development and apply it to their daily life. Warbroek et al. [24] suggested that the key to creating a successful low-carbon community lies in the collective and collaborative efforts of relevant organizations, the local community and the local government. How to enhance the efficient development of clean energy to transform the community energy system to a dual-carbon system is also a currently a hot topic, especially the development of rooftop photovoltaic resources [25–28]. At this stage, the practices of building dual-carbon communities in China is still in the exploratory stage, and academic research classifies communities into three major categories: new urban communities; existing urban communities; and rural communities. There is currently a lack of research on dual-carbon communities with more detailed and regional characteristics.

In the progress of urban planning oriented to stock renewal, historical districts with regional characteristics have become a hot spot for research. As a national historical and cultural city with over 200 years of urban history, the conservation and use of Guangzhou historical and cultural districts can be traced back to the 1930s [29,30]. The current revision of the *Conservation Plan of Historical City of Guangzhou (2021–2035)* emphasizes how to revitalize and protect the city's traditional pattern and overall appearance in the new era [31]. As the most concentrated area of the Guangzhou historical and cultural sectors, Xiguan has numerous historical locations, a privileged geographical position, a moderate level of development, a relatively stable social structure and a rich spatial structure, combining the epitome of the development of urban life and focusing on the personality of Guangzhou city. Therefore, it is of great significance for the urban development of Guangzhou and the whole country to actively explore the path of small-scale and quality micro-renewal of the Xiguan historical and cultural district, focusing on the inheritance and promotion of regional culture.

An extensive amount of research has been carried out on the micro-renewal of historical and cultural districts from different perspectives. Reflecting on the concept of large-scale construction after the Second World War, Jane Jacobs proposed small and flexible urban planning [32]; for progressive regeneration models, Colin Rowe proposed the concept of the collage city [33], using a collage approach to reconnect severed pieces of history in the historical district. In response to China's rapid urban construction after the reform and opening up, Wu [34] criticized these one-sided and arbitrary actions and proposed the concept of organic renewal, advocating the preservation of the integrity of the old city pattern in development. Li [35] argued that contemporary micro-renewal requires low-threshold attributes, people-oriented orientation, and collaboration with broad participation. Deng et al. [36] explored the sustainable development of historical and cultural districts in the future based on the concept of wisdom. While the current research focuses on material aspects, the sustainable development of historical and cultural districts in the future will become an important issue, and there is a lack of understanding on how to summarize and innovate the micro-renewal of historical and cultural districts based on a dual-carbon perspective.

Through reviewing the research progress of dual-carbon communities and micro-renewal of historical and cultural communities, the author summarizes and finds two problems: (1) In terms of dual carbon communities, the current research is divided into three categories: new urban communities, existing urban communities, and rural communities, and lacks research on dual-carbon communities with more detailed and regional characteristics. (2) In terms of micro-renewal of historical and cultural communities, previous studies have mostly focused on the physical aspect, while the sustainable development of old communities in the future will become an important issue. Therefore, this study can complement the research on the relationship between the dual carbon perspective and the implementation path of community micro-renewal, which has important academic significance. As the focus of micro-renewal of Guangzhou's historical and cultural district, Xiguan is the origin of Guangzhou city and has outstanding historical value. The conservation, revitalization and utilization of historical and cultural districts is a major part of Guangzhou urban construction, and has now entered the process of holistic and contiguous conservation and renewal, with a focus on the 14 Xiguan historical and cultural districts. With its extensive coverage, complex historical elements, significant livelihood issues and lack of ecological planning in the early years, it is a key area for dual-carbon planning and construction research. How to spend a small amount of money to do a big job in historical and cultural districts, and how to achieve low energy consumption in terms of function, business type, materials and construction in the process of regeneration are also important steps towards the goal of dual-carbon. This is also of academic importance as it complements research on the relationship between the dual-carbon perspective and community micro-renewal implementation pathways.

2. Materials and methods

2.1. The characteristics of the site

- Guangzhou Xiguan

Guangzhou Xiguan is located in the west of Guangzhou city and is currently mainly under the jurisdiction of the Liwan District Government. In 2006, the *Plan for the Protection of the Traditional District of Xiguan and the Style of Liwan District* first defined the geographical scope of Xiguan as an area of 536 ha from Zhongshan Road (including the Chen Family Temple) in the north, Renmin Road in the east and the Pearl River in the southwest. Thus, the scope of Xiguan as defined by the Liwan District Government, as shown in Fig. 1**(a),** 1**(b)**,1**(c)**.

- Xiguan Historical and Cultural District of Guangzhou

Conservation Plan of Historical City of Guangzhou was approved in 2014, and it delineated 26 historical and cultural districts and 19 historical style areas, of which Guangzhou Xiguan accounts for 14, with a protection area of 2.36 km^2 and a core protection area of 1.41 km^2. Therefore, Guangzhou Xiguan is the most concentrated area of the historical and cultural resources in Guangzhou, and is the focus of the micro-renewal of Guangzhou's historical and cultural districts [37].

- Changhua Street Historical and Cultural District of Guangzhou

Changhua Street Historical and Cultural District of Guangzhou was selected as the study area due to its typical regional cultural characteristics and the high significance of its recent adaptive use. The conservation area of the historical and cultural district of

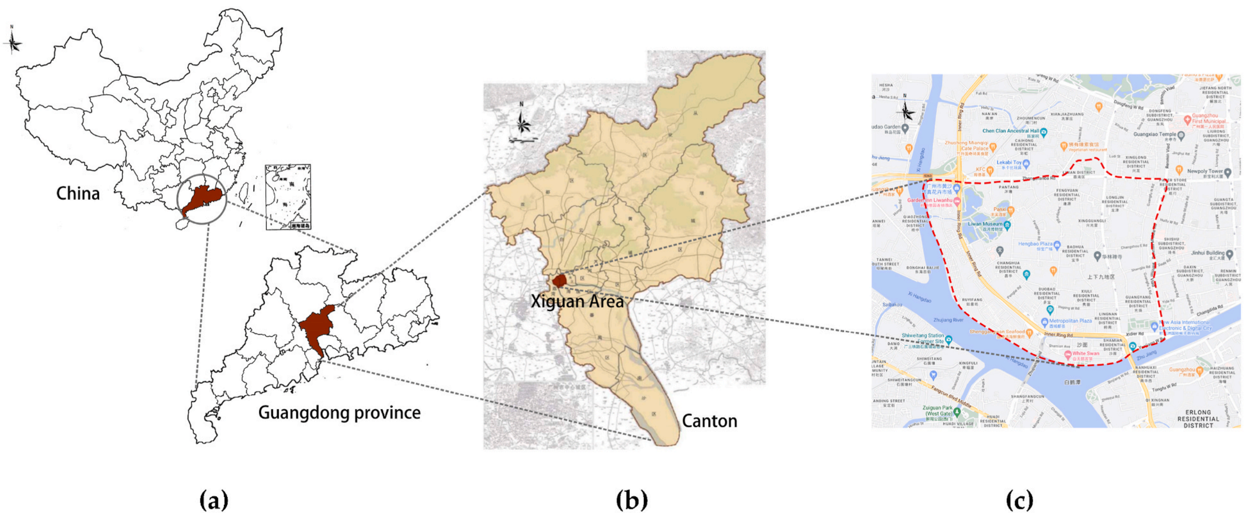


Fig. 1. Maps of the historicalal area of Guangzhou Xiguan. (**a**) Location of Guangdong Province in China and Guangzhou in Guangdong Province; (**b**) Location of Xiguan in Guangzhou; (**c**) The specific geographical location of Xiguan.

Changhua Street, as defined in the *Conservation Plan of Historical City of Guangzho*u in 2014, is 6.05 ha, as shown in Fig. S1.

As one of the 14 historical and cultural districts in Liwan District, Changhua Street is of great historical and cultural value. The community began its conservation and adaptive use in 2022, exploring its dual-carbon development path. This is of great relevance in the study of the relationship between the dual-carbon perspective and implementation path of micro-renewal in historical and cultural districts.

2.2. Data sources and processing

We obtained and analyzed carbon emissions in Changhua Street, which involved on-site spatial research in the community and visits from relevant authorities. The author's team cooperated with relevant government units to participate in the protection, activation and utilization project of the Changhua Street Historical and Cultural District, which provided strong support for the acquisition of the relevant data for this study.

The basic information of the community, such as population size, number of shops, distribution of enterprises and institutions, etc., was obtained by contacting the relevant staff of Changhua Street; the electricity consumption of the community was collected from the Liwan Power Supply Bureau of Guangdong Power Grid Co. The distribution of public green spaces was determined through field research combined with relevant government data. Several field surveys were also conducted in the area, taking photographs, recording the relevant spatial data, and confirming and correcting the existing data.

2.3. Methodology of community carbon emission characterization

2.3.1. Emission factor method

Different scholars, institutions and regions have varying perspectives on CO_2 emissions and have therefore established distinct carbon accounting methods. At present, accounting methods with a wide range of applications mainly include the experiment approach [38], emission-factor approach [39], life cycle assessment (LCA) [40] and the input-output approach [41]. The use of different accounting methods result in large differences in CO_2 emission levels across regions [42–45]. Carbon emission accounting at the community scale has a clear boundary, a relatively micro scale, and relatively clear carbon sources and carbon sinks involved in the sector [46]. Therefore, we refer to the emission-factor approach provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

2.3.2. Accounting for carbon emission

The accounting methodology includes not only the means to quantify carbon sources and sinks, but also the geographical boundaries, GHG types, data collection methods, and accounting report formats. The study area is the Changhua Street Historical and Cultural District, and the three main sectors involved are energy, land-use change and forestry, and waste. The energy sector includes building and the transportation. The demand for carbon emissions caused by parking meetings within the community is mainly derived from external hospitals and schools, and street parking will be completely eliminated at a later stage of the project's planning and implementation. Therefore, the carbon emissions from motor vehicle traffic have an extremely limited impact on the carbon sink within the neighborhood; while residents travel mainly using electric bicycles and walking methods, which do not generate direct carbon emissions. Thus, the carbon emissions from traffic are negligible. The land-use change and forestry sector focuses on public green spaces within the community that absorb and store CO_2 generated by the community. In addition, indirect carbon emissions from wastewater treatment and domestic waste disposal within the community are also addressed. The Kyoto Protocol specifies six GHGs (CO_2, CH_4, N_2O, HFC_S, PFC_S and SF_6). HFC_S, PFC_S and SF_6 are mainly produced by industrial activities and as the scope of this study does not involve industrial activities, only CO_2, CH_4 and N_2O GHG emissions are covered.

Community carbon accounting can refer to the *Greenhouse Gas Accounting Tool for Chinese Cities* by World Resources Institute, which takes the level of carbon emission activity multiplied by a carbon emission factor and accounts for the global warming potential (GWP). Therefore, the basic calculation principle for community carbon accounting is as shown in equation (1) :

$$E = \sum_i L_i \times EF_i \times PV_p, \quad (1)$$

where E is carbon emission; L_i is the level of carbon emission activity; EF_i is the emission factor; and PV_p is the GWP value of the GHG, here the GWP values in the IPCC Second Assessment Report [47] are used, where the GWP value of CO_2 (PV_1) is 1, the GWP value of CH_4 (PV_2) is 21, and the GWP value of CH_4 (PV_3) is 310.

1. Accounting for Carbon Emissions from Buildings

Carbon emissions from buildings within Changhua Street can be categorized into carbon emissions from residential buildings, carbon emissions from shops and carbon emissions from businesses and institutions. The energy sector consumption includes fossil fuel combustion and the input electricity consumption of buildings. The fossil fuel combustion within Changhua Street is dominated by natural gas, with negligible carbon emissions from liquefied petroleum gas, while residential buildings in Guangzhou do not provide energy for heating, and thus input heat consumption is not considered.

As a result, the carbon emissions from natural gas combustion activities within the buildings are measured as shown in equation (2) [15]:

$$E_1 = A_1 \times LC \times CC \times OC \times \frac{44}{12} \times PV_1, \tag{2}$$

where E_1 is the carbon emissions from natural gas combustion activities in buildings (kg); A_1 is the natural gas consumption (m^3); *LC* is the low heating value of natural gas (kJ/m^3); *CC* is the carbon content per unit calorific value of natural gas combustion (tC/TJ); and *OC* is the carbon oxidation rate of natural gas combustion. The *Guidelines* provides default values for the aforementioned data, *LC* value is 38931 kJ/m^3 [15], *CC* value is 15.32 t C/TJ [15], *OC* value is 99% [15].

Carbon emissions from building input electricity consumption are measured as equation (3) [15]:

$$E_2 = A_2 \times EF_2 \times PV_1, \tag{3}$$

where E_2 is carbon emissions from building input electricity consumption (kg); A_2 is the input electricity consumption (kWh); and EF_2 is the mean of CO_2 emission factor. This study adopts the meanCO2 emission factor of the power grid in Guangzhou in 2018 provided by the *Guidelines* (0.6959) [15].

2 Accounting for Plant Carbon Sinks

The green space within Changhua Street is dominated by street trees, of which Lingnan fruit trees and Lingnan common trees dominate, with a relatively even distribution of plants and a small distribution of shrubs and herbs, whose carbon sink can be ignored. The carbon sink of plants in the community is measured as equation (4) [15]:

$$E_3 = \sum_j \left(LAI_j \times netAC_j \times S_j\right) \times PV_1, \tag{4}$$

where E_3 is carbon sink of plants in the community (kg); LAI_j is the leaf area index of the j-th plant; $netAC_j$ is the carbon sequestration per unit leaf area of the j-th plant (kg/m^2); and S_j is the projected area of the leaf crown of the j-th plant on the ground (m^2). Field research and a review of the Conservation and Revitalization of the Changhua Street historical and cultural district - Special Chapter on Tree Preservation revealed that there are up to 31 species of trees in the community, with Lingnan plants such as Bauhinia blakeana, Litchi chinensis and Ficus altissima grandis dominating, where the values of *LAI*, *netAC* and carbon sinks for different plants are as shown in Table S1.

3 Accounting for Carbon Emissions from Waste

The two main components of GHG emissions from waste disposal are those from solid and water waste disposal, respectively.

- Accounting for Carbon Emissions from Solid Waste Disposal

GHG emissions from solid waste disposal consist of CH_4 emissions from the disposal of domestic waste in landfills and CO_2 emissions from the incineration of waste.

1) Carbon emissions from landfill disposal are measured as equation (5) [15] :

$$E_4 = (MSW_T \times MSW_F \times L_0 - R) \times (1 - OX) \times PV_2, \tag{5}$$

where E_4 is the carbon emissions from landfill disposal (kg); MSW_T is the total community solid waste generation (kg); MSW_F is the community solid waste landfill disposal rate; *R* is the CH_4 recovery (kg) ; *OX* is the oxidation factor; and L_0 is the methane production potential of the landfill ($kgCH_4/kg$), which is described as equation (6) [15]:

$$L_0 = MCF \times DOC \times DOC_F \times F \times \frac{16}{12}, \tag{6}$$

where *MCF* is the CH_4 correction factor for the landfill; *DOC* is the degradable organic carbon content (kgC/kg); DOC_F is the degradable *DOC* ratio; *F* is the proportion of CH_4 in the landfill waste gas; *R* is the CH_4 recovery (kg); and *OX* is the oxidation factor.

The estimation of *DOC* is based on the components in domestic waste, and is calculated by the proportion average weight of the degradable organic carbon of each component, as shown in equation (7) [15] :

$$DOC = \sum_i (DOC_i \times W_i), \tag{7}$$

where DOC_i is the proportion of degradable organic carbon in domestic waste type i; and W_i is the proportion of household waste of type i.

The emission factor data described follow the *Guidelines* and relevant government sources, MSW_F value is 23.6% [48], *R* value is 0 [15], *OX* value is 0.1 [15], *MCF* value is 0.4 [15], DOC_F value is 50% [15], *F* value is 50% [15].

The proportions of domestic waste were obtained from a survey on the composition and nature of domestic waste carried out in

Guangzhou in 2021 [49]. The proportions of degradable organic carbon for different types of domestic waste follow the recommended values in the *Guidelines* (Table S2).

2) The carbon emissions from waste incineration are calculated as equation (15) [15]:

$$E_5 = MSW_T \times MSW_I \times CCW_I \times FCF_I \times EF_I \times \frac{44}{12} \times PV_1, \tag{8}$$

where MSW_I is the community solid waste landfill incineration rate; CCW_I is the proportion of the carbon content of waste; FCF_I is the proportion of mineral carbon in the waste to total carbon; and EF_I is the burning efficiency of the waste incinerators.

The emission factor values for the waste incineration treatment refer to the relevant government sources and the recommended values in the *Guidelines*, MSW_I value is 66% [49], CCW_I value is 20% [15], FCF_I value is 39% [15], EF_I value is 95% [15].

- Accounting for Carbon Emissions from Wastewater Treatment

GHG emissions from domestic wastewater treatment include CH_4 and N_2O emissions, and their carbon emissions are measured as equation (9):

$$E_6 = E_{61} + E_{62}, \tag{9}$$

where E_{61} and E_{62} denote the CH_4 and N_2O carbon emissions from the wastewater treatment, respectively.

1) The CH_4 carbon emissions from wastewater treatment are measured as equation (10) [15]:

$$E_{61} = [(TOW \times EF) - R] \times PV_2, \tag{10}$$

where TOW is the total organic matter in domestic wastewater (kgBOD); EF is the emission factor; and R is the CH_4 recovery (kg).

The estimation formula of the emission factor (EF) is as equation (11) [15]:

$$EF = B_0 \times MCF, \tag{11}$$

where B_0 is the maximum CH_4 production capacity; and MCF is the CH_4 correction factor.

The main activity level data of domestic sewage treatment CH4 discharge is the total amount of organic matter (TOW) in wastewater, while biochemical oxygen demand (BOD) is also as an important indicator. In China, only the statistical data of chemical oxygen demand (COD) is available. Therefore, the correlation between BOD and COD provided in the Guidelines is used for conversion, BOD/COD value in South China is 0.47 [15].

The values of the CH4 gas emission factors for domestic wastewater treatment refer to the recommended values in the Guidelines, B_0 value is 0.6 [15], MCF value is 0.6 [15], R value is 0.6 [15].

2) N_2O carbon emissions from wastewater treatment are measured as equation (12) [15]:

$$E_{62} = N_E \times EF_E \times \frac{44}{28} PV_3, \tag{12}$$

where N_E is the nitrogen content in wastewater (kg); and EF_E is the N_2O emission factor for wastewater (kgN_2O/kgN).

The nitrogen content N_E in wastewater can be calculated as equation (13) [15]:

$$N_E = (P \times Pr \times F_{NPR} \times F_{NON-CON} \times F_{IND-COM}) - N_S, \tag{13}$$

where P is the permanent population; Pr is the protein consumption per capita (kg/person); F_{NPR} is the nitrogen content in protein (kg/kg); $F_{NON-CON}$ is the non-consumable protein factors in wastewater; $F_{IND-COM}$ is the protein emission factors for industry and commerce; and N_S is the nitrogen removed with sludge (kg).

The *Guidelines* provide activity level data and emission factors for the N_2O emissions from domestic wastewater treatment, EF_E value is 0.005 kgN_2O/kgN [15], P value is 3463 [15], Pr value is 26.79 kg/person [15], F_{NPR} value is 0.16 kg/kg [15], $F_{NON-CON}$ value is 0.015 [15], $F_{IND-COM}$ value is 0.0125 [15], N_S value is 0 kg [15].

2.3.3. Carbon emission activity level data and carbon emission assessment results

Community carbon emissions relate to the energy and waste sectors. Table 1 reports the related carbon emission activity level data. The data includes the sum of activity level data from November 2021 to October 2022, for a total of 12 months.

Based on the emissions data described above, it is possible to calculate the GHGs and their emission components within the Changhua Street Historicalal and Cultural District, as shown in Table 2. From November 2021 to October 2022, the carbon emission of Changhua Street is 3774670 kg, with a resident population of 3463 people and a per capita carbon emission of 1090 kgCO_2/person; the area occupied by the area is 60,500 m^2. The carbon emission per unit area is 62.39 kg/m^2.

Table 1
Data on carbon emission activity levels on Changhua Street.

Emissions Sector	Carbon Sources		Activity Level Data	Data Sources
Energy sector	Natural gas consumption	Natural gas consumption in households (m^3)	19846	Guangzhou Gas Group Co.
		Natural gas consumption in shops (m^3)	11743	Guangzhou Gas Group Co.
		Natural gas consumption by enterprises and institutions (m^3)	31204	Guangzhou Gas Group Co.
	Electricity consumption	Electricity consumption in households (kwh)	2499708.4	Guangzhou Liwan Power Supply Bureau
		Electricity consumption in shops (kwh)	1663851.39	Guangzhou Liwan Power Supply Bureau
		Electricity consumption of enterprises and institutions (kwh)	384278.5	Guangzhou Liwan Power Supply Bureau
Waste sector	Solid waste generation (kg)		1474190	Estimate
	Total organic matter in wastewater (kgbod)		2950	Estimate

Table 2
Carbon emission data for Changhua Street.

Emissions Sector	Carbon Sources and Sinks	CO_2 (kg)	CH_4 (kg)	N_2O (kg)	CO_2 equivalent (kg)
Energy sector	Natural gas consumption	142120	–	–	142.12
	Electricity consumption	3164840	–	–	3164840
Land-use change and forestry sector	Plant carbon sinks	−18410	–	–	−18410
Waste sector	Solid waste treatment	264350	10270	–	480020
	Wastewater treatment	–	290	0.02187	6100
Total emissions		3552900	10560	0.02187	3774670

3. Results

3.1. Spatial distribution characteristics of carbon emission in Changhua street

The development of dual-carbon micro-renewal strategies for Changhua Street requires an analysis of its carbon emission distribution characteristics. The per capita carbon emissions within the community are 1090 kg CO_2/person. Although the results simplify the carbon emissions of the residents' households, they are much lower than the per capita carbon emissions in China. This can be attributed to the following three reasons: (1) Street morphology: Changhua Street road basically adopts a cross street system and the street direction is mainly east-west. Thus the plan layout of the building is mainly north-south. The layout faces the southeast-oriented summer monsoon in the Lingnan area, which is conducive to ventilation and lighting and reduces resource consumption [50], as shown in Fig. 2. At the same time, Changhua Street is located on the riverfront under the dominant summer wind direction, which can effectively create a microclimate in the neighborhood. (2) Building type: the site is dominated by traditional bamboo houses, which use narrow cold-aisle ventilation to move air throughout the home, thus reducing the temperature inside [51,52]. (3) Resident profile: the community is highly ageing and has a low income. Most residents use public transport to get around and energy consumption tends to fall as income decreases. Thus, energy consumption is relatively low [53,54].

In the community carbon emissions structure, Changhua Street is dominated by energy consumption in buildings, with electricity consumption being the largest, accounting for 83% of total carbon emissions, followed by natural gas consumption at 4% and wastewater treatment at the smallest, with nearly 0% of carbon emissions. Meanwhile, although commercial electricity consumption accounts for 37%, commercial buildings account for only 18% of all community buildings. Therefore, it is significant to consider how to reduce the carbon emissions from energy activities, especially for shops that are mainly in the restaurant sector, and how to improve energy efficiency. Through the electricity consumption data provided by Guangzhou Liwan Power Supply Bureau, summer is the peak period for community electricity consumption, when most residents use air conditioners to cool their homes, resulting in a sharp increase in electricity consumption. This induces the need to enhance environmental eco-efficiency to cope with Guangzhou's hot and humid climate. The carbon sinks of plants only account for 0.48% of the community's carbon emissions, and the carbon sequestration capacity is clearly insufficient. In the stage of micro-renewal, it is necessary to consider how to enhance the carbon sequestration capacity of green spaces in limited public spaces.

3.2. Dual-carbon micro-renewal strategies for historical and cultural district of Changhua street

3.2.1. Renewal of buildings based on property rights and historical values

The buildings in the historical and cultural district have a long history, the ownership status of the houses is complex, and the preservation status and protection level of different buildings vary. This prevents the easy renovation of buildings. It is necessary to map the property rights of the buildings and dispose of them in a categorized manner, taking into account the historical value each building, and using exemplary buildings to gradually guide the dual-carbon micro-renewal of the buildings in the community. The ownership of buildings in Changhua Street is mainly private, while public housing is mostly mixed with private housing, as shown in

Fig. 2. Site texture map of Changhua Street.

Fig. 3**(a)**. The public houses, as the more mature ownership units, can undergo small-scale progressive dual-carbon micro-renewal according to the design guidelines. In contrast, for private houses, the wishes of the residents need to be respected, and cooperation with the government for renovation and renewal is encouraged. In terms of the historical value, there are different levels of buildings within Chang Hua Street, as shown in Fig. 3**(b)**, which require appropriate dual-carbon development strategies based on the carrying capacity of the housing renovation. Combined with the basic situation of the buildings on Changhua Street, six design classification disposal patterns can be summarized, as shown in Fig. 3**(c)** and Table 3.

Dual-carbon buildings are both active and passive. Choosing passive energy-saving for conservation objects has greater ecological and economic benefits.

Ordinary buildings can adopt active energy-saving methods and introduce energy-saving technology and equipment to improve the dual-carbon benefits of buildings, as shown in Table S3.

3.2.2. *Upgrading of municipal facilities based on balance of interests*

Due to the lack of long-term planning of the early infrastructure, upgrading of municipal facilities is a key yet complicated task in the micro-renewal of historical and cultural districts. Moreover, the high investment cost of the project makes it difficult to obtain high returns in the short time in terms of dual-carbon systems. However, the upgrading of municipal facilities requires a balance between immediate and long-term benefits, particularly for municipal pipelines and traffic systems, where a single renovation can bring long-term benefits.

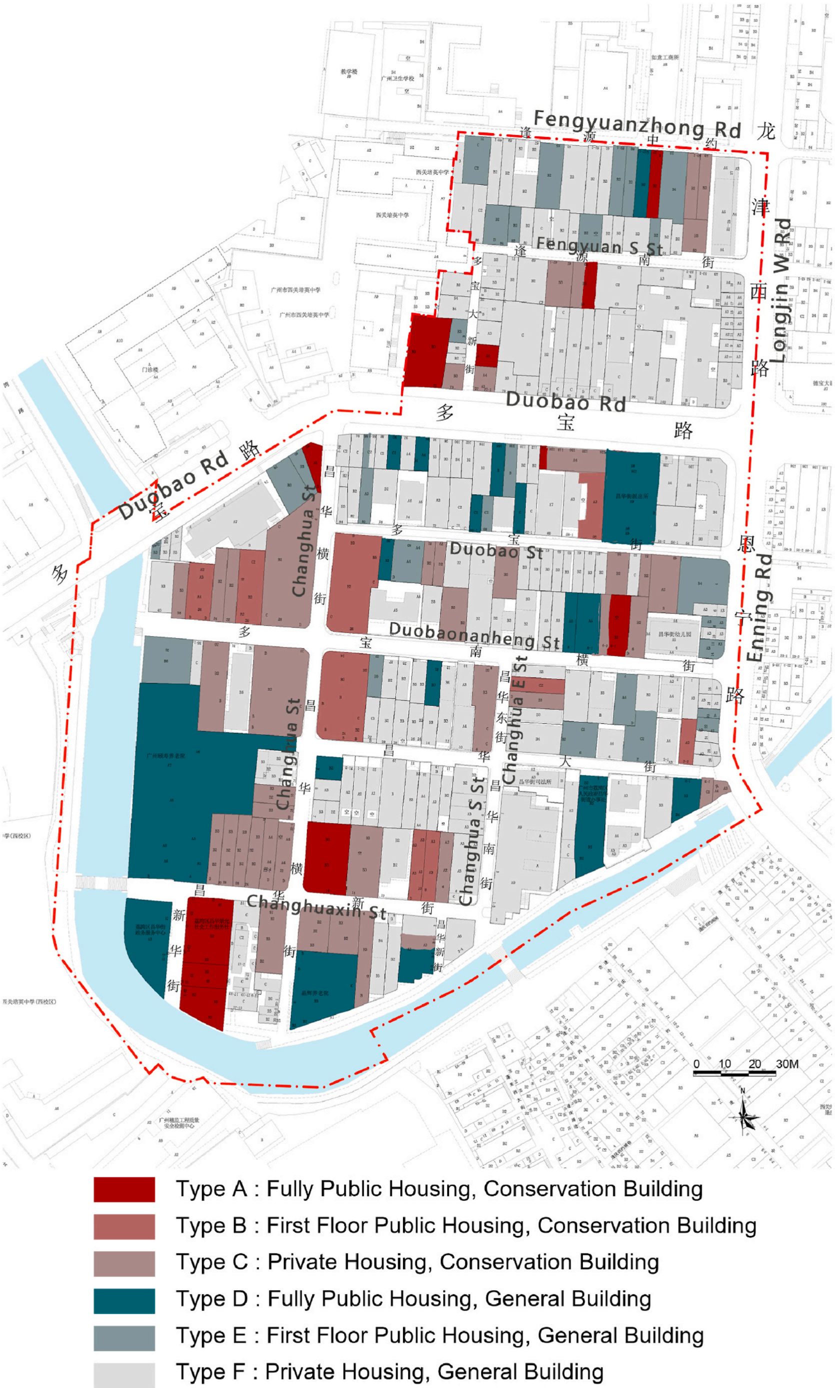
Based on the road and implementation conditions, a micro comprehensive pipe tunnel system is proposed for the main roads of the community. This can improve the carrying capacity of the municipal infrastructure of the historical district, avoids the carbon emission caused by the frequent municipal repair that induces resource consumption, prevents the frequent excavation of the road surface for maintenance, and protects the historical style [55,56]. The scheme does not change the current sewage pipeline system, and the types of pipelines entering the corridor are water supply, electricity and communication pipes. The size of the comprehensive tunnel is 1.5 m $\times$ 1.4 m, with the left and right sides considered in accordance with the 3-layer support，as shown in Fig. 4**(a)**,4**(b)**. This is convenient for the maintenance and management of the pipelines, and reserves ground space for the plant carbon sink sites on the main roads.

In terms of the traffic system, due to the narrow streets of Changhua Street, the double parking method results in a small safe distance for staggered traffic, and the carbon emissions generated by car traffic jams are greatly increased. In order to slow down the shortage of motor vehicle parking spaces, an underground public car park is planned for the west side of the site in the long term. The car park is proposed to cover an area of about 1065 m^2, including three levels and approximately 127 parking spaces. During the construction of the car park, the original fixed motor vehicle parking spaces will be re-planned and set up uniformly on one side to reduce the impact on the appearance of the main conservation buildings. This will also mitigate the carbon emissions caused by the long meeting time.

3.2.3. *Street revitalization based on climate adaptation*

The climate of Guangzhou is hot, humid, windy and rainy [57]. A suitable outdoor thermal environment can encourage residents to participate in outdoor activities, thereby reducing building energy consumption. Changhua Street has been developed as a

Fig. 3. Building condition map of Changhua Street. (**a**) Distribution of building ownership on Changhua Street; (**b**) Distribution of buildings in the category of conservation objects on Changhua Street; (**c**) Distribution of dual-carbon building types.



(c)

Fig. 3. (*continued*).

climate-resilient street through the installation of an elevated community center, the addition of street trees to the main street and the construction of a sponge system.

The ground floor of the public housing will be de-raised and set up as a public activity center (Fig. 5), linking the street to the waterfront space. Part of the alleyway will also be de-railed to open up the inner street, which will enhance street ventilation and create a local microclimate, while also restoring the original historical texture of Changhua Street. The community green space assumes the main carbon sink, burying some of the pipes in the micro comprehensive tunnel and releasing the street space. Additional trees will be

Table 3
Disposal patterns for the design classification of dual-carbon retrofits in buildings.

Dual-carbon Building Types	Building Retrofit Features	Dual-Carbon Building Technology
Type A: Fully public housing, conservation building	① Conservation rating and load-bearing capacity	Simple green roof, tramble wall, insulation under roof frame, window film, rainfall pipe installation
Type B: First floor public housing, conservation building	① Conservation rating and load-bearing capacity ② Incorporation of dual-carbon energy efficiency measures on the first floor	Window film, first floor green shading
Type C: Private housing, conservation building	① Low potential for renovation ②Guiding households to revitalize in partnership with the government	Window film, cooperation with the government to strengthen and reinforce the original structure
Type D: Fully public housing, general building	① Use of active energy efficiency to form exemplary buildings	Trumbull walls, solar photovoltaic modules, intelligent control
Type E: First floor public housing, general building	① Moderate potential for conversion ② Linking the ground floor of the building with the outdoor space to create a dual-carbon space	Linkage with outdoor spaces to form point rain gardens, vertical greenery on the first floor
Type F: Private housing, general building	① Low retrofitting potential. ②Proposing a dual-carbon retrofit to guide households to retrofit themselves	Rainfall pipe installation, intelligent control

planted on the main street to increase the street shade space using high carbon fixing native plants. The sponge system consists of permeable paving, sunken grass swales and rain gardens, which reduce total runoff and runoff pollution loads from 0.84 to 0.82 [58].

3.2.4. Dual-carbon steering based on multi-participant participation

The dual-carbon micro-renewal of Changhua Street not only requires a suitable spatial design, but also guidance in the entire decision making, design, implementation and utilization processes, which involves the management, implementation and utilization of the subject [59,60].

The local government, as the management body, provider of information and the decision maker of the scheme, needs to establish a system of dual-carbon indicators for the community and guide the designer in developing a positive and negative list of dual-carbon revitalization.

As the project is within a residential cluster, the civilized and green construction of the implementation body, also known as the construction team, is particularly important. They need to be guided to develop at a low intensity and reduce carbon emissions during the renovation process.

As the main users, residents are guided to change from passive to active dual-carbon, from hoping on the government to sharing the responsibility [7]. For example, residents should be encouraged to use community drying spaces to dry their clothes and reduce electricity consumption, and also adopt the "CarbonWise" platform to spread the concept of dual-carbon into their lives. In addition to individual participation, social governance should also be initiated, for example, by neighborhood committees or resident groups initiating plant exchange activities and eco-garden planting in waterfront spaces.

4. Discussion

There are currently limited studies on the characteristics of carbon emissions and dual-carbon strategies in the renewal of historical and cultural districts, resulting in a large scientific gap on how to build a sustainable historical district. Therefore, this study attempts to explore the dual-carbon construction strategy of Changhua Street based on the community's carbon emissions from the perspective of spatial and non-material forms. We then deduce the dual-carbon implementation path in the micro-renewal process of the Xiguan historical and cultural district of Guangzhou.

4.1. Principles of dual-carbon micro-renewal based on the regional characteristics of the Xiguan district

Through the study of the dual carbon micro-renewal of Changhua Street, the principles of constructing the Xiguan Historical District of Guangzhou from a dual-carbon perspective can be summarized as the following three points: (1) Control of the style: the dual-carbon micro-renewal must focus on the preservation and continuation of the characteristic style of the historical and cultural district, avoiding the loss of its cultural values in the pursuit of its economic and commercial development. (2) Low cost: Small-scale, incremental micro-renewal means that the community needs to be progressively renewed in a smart and low-budget manner. The conservation and repair of heritage buildings as well as the revitalization and renewal of historical streets involve a large number of engineering modifications, so it is crucial to balance the effectiveness of the renovation with the budgetary investment for the sustainability of the long-term strategy [61]. (3) Emphasis on people's livelihoods: Historical districts generally have ageing buildings and poor infrastructure, yet they are still living spaces for local residents. Thus, the micro-renewal of historical districts is closely related to people's livelihoods, and needs to account for the climate adaptation of the district as well as the renovation of basic municipal facilities.

4.2. The Implementation Path of dual-carbon micro-renewal in Guangzhou Xiguan Historical District

Dual-carbon micro-renewal in historical and cultural districts is a dynamic and long-term development process with high construction requirements, encompassing a wide range of elements and covering more systems in the community. Science, rationality and operability are essential principles for this, and therefore this study proposes an implementation path for the Xiguan historical and cultural district of Guangzhou.

4.2.1. The accounting of community carbon emissions

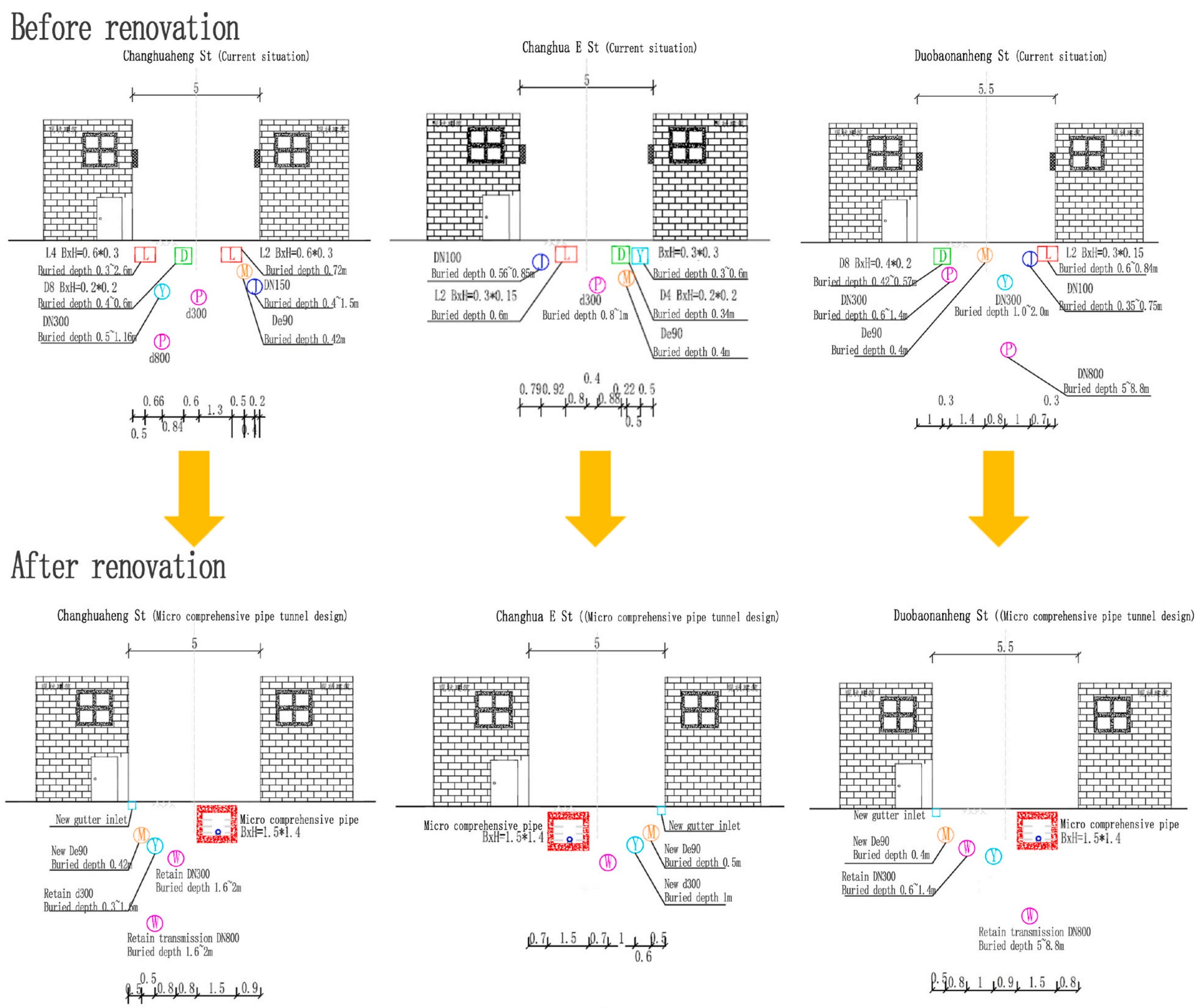
The first steps in building a dual-carbon community are to account for the community's carbon emissions, analyze the distribution characteristics of the community's carbon emissions, and investigate the key operational sectors affecting the construction of the dual-carbon community. This will assist in the construction of the evaluation technology system and the regulation of carbon emissions in the construction of the dual-carbon community system at a later stage. We take the emission factor from the *Guidelines*. Section 2 above describes in detail the methodology for the study of the carbon emission characteristics of Changhua Street, which can be applied to the Xiguan historical and cultural district of Guangzhou.

4.2.2. Constructionof the evaluation index system

To measure the level of construction and progress of a dual-carbon community, it is necessary to build an indicator system and evaluation criteria for the development of a dual-carbon community, based on which appropriate measures and actions can be selected

(a)

Fig. 4. Design of micro comprehensive tunnel systems. (**a**) System plan. (**b**) Street section.



(b)

Fig. 4. (*continued*).

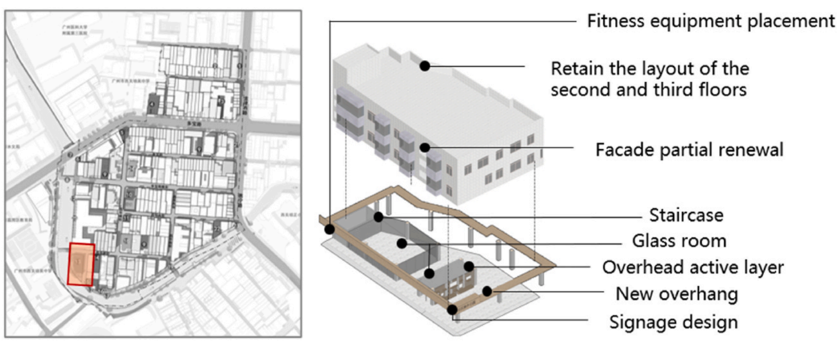


Fig. 5. Diagram of the elevated activity center.

to further optimize the construction path of a dual-carbon community [62]. In 2019, the Guangdong Low Carbon Development Promotion Association released the *Evaluation Criteria for Low Carbon Livable Communities*, the framework of which is shown in Table S4. This evaluation indicator system can be adopted for the Xiguan historical and cultural district of Guangzhou, while the system can be optimized and adjusted according to the current situation of the historical district characteristics (Table S5).

4.2.3. Establishment of the dual-carbon community system

The investigation of the community's carbon emissions and the construction of the evaluation technology system reveal the requirement to improve the working basis and overcome limitations of elements such as transportation, energy, water resources, greening and solid waste. Thus, it is necessary to have an in-depth understanding of the wishes and needs of various subjects, so as to clarify the micro-renewal objectives and propose specific index requirements, and to determine the implementation strategies and plans for the micro-renewal of historical and cultural districts. After the completion of the project, publicity and guidance must be actively conducted within the community and residents should be invited to conduct community participation and evaluations in order to form a full-cycle micro-renewal of the historical and cultural district with feedback links [63].

4.2.4. The planning of the dual-carbon spatial pattern

In addition to the dual-carbon design within the historical and cultural districts, the dual-carbon micro-renewal should be integrated with the Xiguan Historical District, particularly the dual-carbon spatial pattern with the city's infrastructure [64]. The historical districts are built-up environments and must be planned based on the existing environment. This can be started by improving the transport system and the surrounding ecological network system. Considering the close association of each community at the scale of the overall area, the transport layout is improved to form a convenient and efficient urban public transport system [65]. It is also crucial to identify important ecological spaces around the area, such as Liwan Lake Park and the Pearl River back channel, and to enhance the ecological network system around the historical and cultural districts in conjunction with the city's green space system planning. This can help to form a blue and green spatial pattern and enhance the environmental and ecological effectiveness of the area.

5. Conclusions

Taking Changhua Street as an example, this study determines and analyses the corresponding carbon emissions from November 2021 to October 2022, and evaluates the structure of the emission sources. The results show that the carbon emission per unit area is 62.39 kg/m^2 and the per capita carbon emission is 1090 kgCO_2/person, which is much lower than the per capita carbon emission in China. Electricity and natural gas consumption are the main sources of carbon emissions in the community. Thus reducing energy consumption is the focus of building the dual-carbon community.

This study then explores the dual-carbon micro-renewal strategy of Changhua Street based on the carbon emission characteristics of the community. In terms of building renovation, the dual elements of the housing ownership and historical value should be combined for energy-saving and emission-reducing renewal. Municipal facilities are closely related to people's livelihoods, and improving the carrying capacity of municipal infrastructure means that carbon emissions from resource consumption due to municipal emergency repairs can be effectively reduced. Hence, a single renovation can have long-lasting benefits. In the face of the hot and humid climate of Guangzhou, the revitalization of streets must be performed through climate adaptation mechanisms, with a view to creating local microclimates and enhancing the carbon sink of green spaces. In addition to the creation of spatial forms, the construction of dual-carbon communities also requires the active guidance of multiple actors in the entire decision-making, design, implementation and utilization processes.

Finally, for the scope of the Xiguan historical and cultural district of Guangzhou, three major principles of dual-carbon micro-renewal are proposed: maintaining the style, low cost, and emphasizing people's livelihoods. We also construct a micro-renewal implementation path for the Xiguan historical and cultural district of Guangzhou, namely accounting for community carbon emissions, constructing an evaluation index system, building a dual-carbon community system and planning a low-carbon spatial pattern. This will provide constructive guidance for dual-carbon micro-renewal in the Xiguan Historical and Cultural District.

Author contribution statement

Minzhi Li: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data. Chuxin Feng: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article/supp. Material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.heliyon.2023.e19552.

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