Research article

Factors facilitating the development of low-carbon cities: evidence from China’s pilot cities

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ABSTRACT

As the largest developing country, China has recognized the importance of low carbon cities. To date, three batches of low-carbon pilot provinces and cities were presented by the Chinese government from 2010 to 2017. Therefore, the local governments in the pilot group should take effective measures to promote the development of low-carbon cities. However, because of the lack of experience in implementing special policies for low-carbon cities, many local governments have encountered difficulties in promoting the development of low-carbon cities. This study critically analysed various policies promulgated during 2010–2021 by the Chinese local governments. The most relevant programming policies of pilot cities were selected. A multidimensional framework is developed to better understand the policies in facilitating low-carbon city development in China. The results showed that there are 16 factors at both the macro level and the micro level that affect the development of Chinese low-carbon pilot cities. The successful promotion of China’s low-carbon cities requires combined efforts from all related stakeholders. In addition, the development of pilot cities is actively promoted by the Chinese national government and linked to other strategic initiatives, such as “peak carbon” by 2030 and “carbon neutral” by 2060. The findings help to better understand the landscape of policy measures of low-carbon city development in China and provide useful references for policy making in other countries.

1. Introduction

As the largest developing country, China’s urbanization rate is in the rapid growth phase, and the urban population will account for 70% of the total population by 2030 (SCC, 2017). The increase in carbon emissions is caused by urban population growth. Therefore, sustainability and low carbon development have become the focus of the Chinese government, and the importance of a “low carbon city” has also been recognized. Furthermore, to achieve “peak carbon” by 2030 and “carbon neutral” by 2060, a series of new policies and regulations were issued by the Chinese government in 2020 (China Daily Online, 2021). National ministries and local governments further emphasize the development of low-carbon cities, emission reduction measures and climate change response (MEE, 2020).

Pilot city guidance is an important measure for the development of low-carbon cities in China. At the beginning of 2008, Shanghai and Baoding became the first cities to join a new World Wildlife Fund (WWF) initiative to explore low carbon development strategies for China’s urban areas (Khanna N et al., 2014; WWF China, 2008). To date, three batches of low-carbon pilot provinces and cities were presented by the Chinese government from 2010 to 2017, and the total number of China’s low-carbon pilot provinces and cities has reached 87. According to the “Notice on the pilot project of low carbon provinces and cities” issued by the National Development and Reform Commission (NDRC, 2010, NDRC, 2012, NDRC, 2017), various elements need to be developed by the pilot cities, such as low-carbon plans, GHG emissions control, low-carbon lifestyle, responsibility system of emissions, and consumption pattern.

Five years have passed since the last batch of pilot cities was promulgated, and Chinese local governments of the pilot provinces and cities have adopted various measures to achieve low-carbon development. The special programming of pilot cities is one of the proven methods to reduce carbon emissions by management measures from the macro- to microscale. Therefore, we examine the relevant low-carbon programming to build a complete management structure for carbon reduction measures. The findings will provide useful references for low-carbon urban development in other countries.

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The paper is structured as follows. Section 2 presents a brief review of recent literature related to the development of low-carbon cities. Section 3 gives an overview of the materials and methods, including special planning screening, policy content analysis, and a summary of policy measures. Section 4 presents our findings, including the management measures from the macro level to the micro level. Section 5 presents the discussion of key issues that must be addressed in low-carbon city practice. Section 6 draws the conclusion of this study.

2. Literature review

In previous studies, city planning, low-carbon governance, and emission assessments were the three common aspects that were investigated in the development of low-carbon cities.

From a city planning perspective, Liu et al. (2014) proposed the use of metabolic thinking and eco-cycle models derived from the discipline of industrial ecology to support urban planning. Hao (2014) probed the principle spatial units of low-carbon city planning, and the mechanisms of the ecological and social systems of low-carbon cities. Liu et al. (2017a, 2017b) developed a model to address the planning challenges between regional planning and the regional economy. Khanna et al. (2014) suggested that 8 pilot cities have made solid progress in establishing low-carbon plans. With the increasing of pilot practice of low carbon cities, pilot city planning is studied by various scholars in China. An Pan et al. (2022) explored the low-carbon innovation which significantly promoted by China’s low-carbon city pilot programming. Wang et al. (2022) examined the impact of China’s low-carbon city pilot on land transfers in high-energy-consumption industries. Wang and Yang (2022) found that the low-carbon city pilot programming has a significantly negative effect on stock return. Shen and Wang (2022) tested the direct effect and indirect effect of low-carbon city pilot programming on greenhouse efficiency of China’s cities.

The government plays a guidance role in the low-carbon governance process in China. Liu et al. (2017a, 2017b) analysed the framework of China’s low-carbon governance by using Suzhou Industry Park as a case study. Wang and Chang (2014) examined the development of policy instruments that support low-carbon governance in China. The instruments are analysed in five aspects in relation to the key policies in low-carbon governance in China, including energy conservation, developing new energy, reforestation, developing a circular economy, and industry restructuring. Peng and Bai (2018) found that the city’s low carbon initiatives are embedded and integrated into its existing policy frameworks. There is a strong vertical linkage between the central and the local governments, where a top-down design is met with bottom-up innovation and enabling mechanisms. Zou et al. (2022) proposed that the governance process of “low-carbon city” pilot can improve the overall technological innovation capability of the city. Du et al. (2022b) examined the low-carbon governance practice from a dimensional perspective to identify the weak area in 35 sample Chinese cities. Liu and Xu (2022) found that the implementation of low-carbon pilot cities can promote the green transformation of residents’ lifestyle. Li et al. (2022) explored the impact of a low-carbon city pilot policies on the synergistic governance efficiency of carbon and smog. Zhang et al. (2022) found convincing evidence on the effectiveness of government-led low-carbon city policy in a developing country.

In addition, studies have been undertaken at the emission assessments of low carbon cities. Liu and Qin (2016) explored the related aspects of low carbon city emissions from the perspective of building energy efficiency, green building, manufacturing and transportation. Zhou et al. (2015) developed an ecological and low-carbon indicator tool for evaluating cities. Shen et al. (2018) proposed a city development-stage framework to assess different driving factors of urban carbon emissions at different stages of city development. Furthermore, Li et al. (2018) investigated the progress of China’s 32 pilot cities from the initial two batches. This study establishes an assessment system to identify effective of local low-carbon experiments. Similarly, Shi and Xu (2022) evaluated China’s pilot low-carbon city program from the perspective of carbon emission efficiency of industry. Zhou et al. (2022) analyzed the impact of China’s low-carbon city pilot policy on enterprises’ emission reduction. Du et al. (2022a) proposed that the pilot policy can significantly improve the carbon emission efficiency and has long-term dynamic effects. Huo et al. (2022) explored the effects of China’s pilot low-carbon city policy on carbon emission reduction, and proposed the pilot cities reduced carbon emissions annually by approximately 2.72%. Meanwhile, Wen et al. (2022) estimated that the low-carbon city pilot policy can significantly improve the carbon emission efficiency of the pilots by 6.6%.

According to the literatures above, scholars have studied the development of low-carbon cities from multiple perspectives in China. However, there is still a lack of research on the policy contents of low-carbon pilot cities, especially special programming policies. Special programming policies directly guide the development of low-carbon cities. On the one hand, it has effects on the city’s positioning, development targets and indicator constraints. On the other hand, it can promote the implementation of low-carbon measures in industry, economy, energy and transportation. Therefore, this study searched all the promulgated special programming policies for low-carbon pilot cities in China and conducted in-depth research on the contents of the special planning policies to fill the gap in this field.

3. Materials and methods

The research procedure and methods in this paper are shown in Figure 1.

In this study, the websites of local governments of 87 pilot provinces and cities were used to collect the relevant pilot policies. According to the degree of relevance between the policy topics and the driving factors of low-carbon cities, the most relevant policies were identified. Through screening, it is found that special programming for low-carbon cities directly promotes the low-carbon development of pilot cities. Meanwhile, special programming can be distinguished from the existing urban planning systems of “Master Planning”, “Regulatory Detailed Planning”, and “Construction Detailed Planning” in China. The special programming mainly refers to a series of plans focusing on specific industries and fields, which is an important programmatic document for the government to guide economic and social development (Xu, 2019). Therefore, the special programming we studied is the special policy issued by the local government for the development of low-carbon cities. On the one hand, the policies of the central government have a guiding effect on local governments. For example, the three batches of low-carbon city pilot policies in China are issued by the National Development and Reform Commission, and the implementers are the local governments of the pilot cities. On the other hand, local governments can match the central policies through the promulgation of their own special policies and put forward various measures to implement the low-carbon development of the city.

As a result, the most relevant programming policies issued by local governments were selected. It is found that 15 cities have issued special programming of low-carbon cities. These 15 cities can be regarded as representative of the programming study, namely, Ankang, Changsha, Hefei, Ningbo, Yinchuan, Guilin, Suzhou, Jinan, Liuzhou, Qingdao, Zhuzhou, Gouqi Qijiang, Xiamen, Shenzhen and Nanchang, and the spatial distribution of these cities is shown in Figure 2.

Furthermore, special programming can be divided into low-carbon development programming and low-carbon implementation programming of a city. The related information of programming policies is shown in Table 1.

There are three types of qualitative content analysis, namely, summative content analysis, conventional content analysis and directed content analysis (Hsieh and Shannon, 2005; Zhao et al., 2019). Conventional content analysis is generally used to describe a phenomenon. Therefore, the advantage of the conventional approach to content
analysis is gaining direct information from study participants without imposing preconceived categories or theoretical perspectives. Sometimes, existing theory or prior research exists about a phenomenon that is incomplete or would benefit from further description. As a result, the goal of a directed approach to content analysis is to conceptually validate or extend a theoretical framework or theory. Typically, a study using a summative approach to qualitative content analysis starts with identifying and quantifying certain words or content in text with the purpose of understanding the contextual use of the words or content (Hsieh and Shannon, 2005). In this paper, summary content analysis was used for those programming policies of the 15 cities, and the texts of these policies were systematically analysed. Subsequently, a comparison method was used to analyse and compare the summarized contents (Siggelkow, 2007). Finally, the policy measures of low-carbon urban programming were summed from the macro level to the micro level, and the contents were studied in detail.

4. Results

The content analysis of programming policies highlighted a list of 16 factors influencing the success of low-carbon pilot cities in China. These factors are classified into two levels: the macro and micro levels. The micro level can also be considered the pilot project level.

4.1. Macro level

4.1.1. City positioning

A reasonable city positioning can clarify the development orientation of a low-carbon pilot city. In the early stages of city programming in China, the characteristics of a city will be critically screened and positioned. There are various factors that can be scientifically positioned in a city, such as the size of urban population, land use, city construction, economic status, industrial level and comprehensive competitiveness (Shanghai Gov, 2017). Similarly, a low-carbon pilot city positioning covers different perspectives. Traditional industrial cities are mainly positioned as cities with high-quality transformation of new industries (Liuzhou Gov, 2019). Meanwhile, cities with ecological resources can be positioned as low-carbon tourism service and green circular agriculture cities (Guilin DRC, 2017). Cities with various advantages can be positioned as, for instance, the subcentre of the Yangtze River Delta, national industrial agglomeration area, international innovation city, national comprehensive transportation hub and national eco-cultural tourism city (Hefei DRC, 2019). On the one hand, the positioning of the city needs to achieve the objectives of ecological, low-carbon and green development. On the other hand, from the perspective of the characteristics of the cities, it is necessary to ensure the integration of the city’s multiple elements, such as the inheritance of urban traditions, the development of humanities and society, ecological potential and economic growth.

4.1.2. Target guidance

The essential target of low-carbon development is to reduce carbon emissions. Therefore, the targets of pilot cities are reflected by CO2 emissions per unit GDP and divided into the general target, phasing target and peaking target. The relationship between the different types of carbon emission targets is shown in Figure 3. The general target is the expected emission target at the end of the planning period. Meanwhile, the phasing targets are the objectives of a specific year based on the general target. According to the planning of Hefei, there are two phasing targets. The first target is the reduction of CO2 emissions per unit GDP in 2020 compared with 2018, and another target is this indicator in 2025 compared with 2020 (Hefei DRC, 2019).
Furthermore, the total carbon emissions are predicted to reach a peak target during the planning period. As a typical case, the total emissions and per capita carbon emissions in Ankang are forecasted to reach the peak target in 2028 (Ankang Gov, 2018). This means that the predicted values of total CO2 emissions and per capita CO2 emissions will reach 10.65 million and 3.95 tons, respectively, in 2028. In China, carbon emission targets can be presented in the form of numerical indicators (Changsha.gov, 2019). As shown in Table 2.

To achieve the total emission target, the Chinese government has put forward special targets in various fields. In fact, the special target is to decompose the carbon emission target into operational and assessable factors. As a result, carbon emission targets are allocated to different

![Figure 2. Distribution and research scope of pilot cities and provinces in China (sourced from policies and drawn by the authors).](image)

| Cities       | Effective period | Document types                                           | Issue by |
|--------------|------------------|----------------------------------------------------------|----------|
| Ankang       | 2018–2030        | Low carbon development programming                       | MG       |
| Ningbo       | 2016–2020        | 13th Five-Year Plan for low carbon city development      | MG       |
| Changsha     | 2018–2025        | Low carbon development programming                       | MG       |
| Yinchuan     | 2017–2020        | Low carbon city development programming                  | DRC      |
| Hefei        | 2018–2025        | Low carbon city development programming                  | DRC      |
| Liuzhou      | 2017–2026        | Low carbon development programming                       | DRC      |
| Qingdao      | 2014–2020        | Low carbon development programming                       | DRC      |
| Suzhou       | 2014–2030        | Low carbon development programming                       | MG       |
| Shenzhen     | 2011–2020        | Long-term programming for low carbon development         | DRC      |
| Guilin       | 2016–2020        | 13th Five-Year Plan for low carbon city development      | DRC      |
| Zhuzhou      | 2018–2023        | Low carbon pilot implementation plan                     | LAO      |
| Jinan        | 2018–2020        | Low carbon development implementation plan               | MG       |
| Gouqingsheng | 2016–2025        | Low carbon pilot implementation plan                     | GIO      |
| Nanchang     | 2011–2020        | Low carbon development programming                       | MG       |
| Xiamen       | 2011–2015        | Low carbon pilot implementation plan                     | DRC      |

DRC: Development and Reform Commission; MG: Municipal Government; LAO: Legislative Affairs Office; GIO: Government Information Office.
departments in a city. The special targets of low-carbon urban programming can be summarized as 7 aspects. As shown in Table 3.

4.1.3. Indicator constraints

Based on target guidance, Chinese local governments have issued various indicator systems to support the development of low-carbon cities. The establishment of these indicators can follow several rules. First, the indicators must be applied to the characteristics of various cities. The basic factors related to low-carbon city development should be included, such as energy, environment, resources, low-carbon society and green finance (Xinhua News Agency, 2018). Second, relevant indicators must be practical and operable in urban management. The third aspect is that the indicators are assessable. They can not only be assessed through reasonable approaches but also provide effective guidance for the implementation of low carbon planning. In addition, the indicator types can be classified into constrained and anticipatory indicators. The constrained indicators are direct and mandatory indicators to measure the low carbon development of a city. Meanwhile, the other indicators

Table 2. Key indicator system of Changsha low carbon programming (2015–2025).

| Indicators                                      | 2015      | 2017      | 2020      | 2025      |
|------------------------------------------------|-----------|-----------|-----------|-----------|
| Total carbon emissions (thousand tons)         | 63,650    | 68,590    | 71,280    | 72,540    |
| CO2 emissions per unit of GDP (tons/thousand Yuan) | 0.0737    | 9.6 percent decrease | 28 percent decrease | 45 percent decrease |
| Energy consumption per unit of GDP (tons of standard coal/thousand Yuan) | 0.0353    | 9.62 percent decrease | 16 percent decrease | 30 percent decrease |
| Carbon emissions per capita (tons/person)      | 8.56      | 8.66      | 8.10      | 7.25      |

Note: Sourced from Changsha.gov (2019) and compiled by the authors.

Table 3. Specific targets and contents of low-carbon city programming.

| Special targets                                      | Sub targets                                                                 |
|------------------------------------------------------|-----------------------------------------------------------------------------|
| Establishing low carbon industry system               | ● Developing low-carbon service industries and strategic emerging industries. |
|                                                      | ● Supporting the transformation to low carbon industries.                   |
|                                                      | ●Constructing industrial agglomeration parks of low-carbon service industries. |
|                                                      | ● Introducing high-level research institutions and advisory services for low-carbon development. |
|                                                      | ● Establishing modern low-carbon industrial system with high scientific and technological content, low resource consumption and low environmental pollution. |
| Improving the status of energy utilization           | ● Restructuring the energy mix.                                              |
|                                                      | ● Controlling coal consumption.                                              |
|                                                      | ● Developing zero carbon emission demonstration projects.                    |
|                                                      | ● Increasing the proportion of clean energy, such as natural gas, solar, biomass and wind. |
| Facilitating low carbon lifestyle                    | ● Promoting residential waste separation systems.                           |
|                                                      | ● Guiding the green consumption of residents.                               |
|                                                      | ● Increasing low carbon publicity and popularizing low carbon concepts.     |
| Promoting energy efficiency in buildings             | ● Improving green standards of new buildings.                                |
|                                                      | ● Enhancing energy-saving renovation of existing buildings.                 |
|                                                      | ● Constructing green town and energy-saving infrastructure.                 |
|                                                      | ● Facilitating the construction of new green residential area and housing industrialization. |
| Improving ecological conditions                       | ● Facilitating the development of city carbon sink.                         |
|                                                      | ● Enhancing ecological restoration and wetland protection.                  |
|                                                      | ● Strengthening the ecological resource management.                         |
| Implementing low carbon transportation strategy      | ● Improving traffic utilization efficiency.                                  |
|                                                      | ● Encouraging the public transport, clean energy transport and smart transport. |
|                                                      | ● Developing convenient, efficient and low-carbon transport systems.         |
| Developing green finance                             | ● Improving green financial infrastructure.                                  |
|                                                      | ● Introducing green finance policy mechanism.                               |
|                                                      | ● Conducting green business project certification.                          |
|                                                      | ● Facilitating the infrastructure construction according to the green finance policy. |
|                                                      | ● Providing government subsidies and discount interest for green financing demonstration. |

Note: Sourced from the 15 low-carbon cities programming and compiled by the authors.
are expected and are used to support the achievement of the constrained indicators. According to our study and summarization, the indicator system suitable for low-carbon city development is shown in Table 4.

### 4.1.4. Economic incentives

To increase economic support for low-carbon development, the Chinese government has issued a series of incentive policies in recent years. The source of financial capital is the special funds established by the governments of all levels. Accordingly, financial capital supports low-carbon city construction through direct subsidies, tax relief, loan discounts and other means (Zhao et al., 2019). Related projects supported by these funds cover the circular economy, low-carbon industries, carbon reduction technologies, energy saving and emission reduction (ShenzhenDRC, 2013).

In addition, to develop a diversified financing mode for low-carbon cities, local governments are encouraged to strive for various subsidies from the state, private capital, foreign capital and other ways. Furthermore, banks and other financial institutions are encouraged to provide financial services to promote the development of low-carbon cities (Guilin DRC, 2017). Meanwhile, advantaged enterprises are encouraged to use multilevel capital markets to list at home and abroad to promote international cooperation and seek financial support from international organizations related to climate change and low-carbon development (Guilin DRC, 2017; Zhuzhou.gov, 2018).

### 4.1.5. Regulations for industrial development

In recent years, the Chinese government has transformed the mode of economic development and developed a circular economy, which has led to the transformation of a large number of industries. First, cities’ traditional industries are facing elimination, such as the metallurgical, paper and chemical industries (Nanchang.gov, 2011). In addition, the promotion of emerging industries in multiple categories is receiving attention from local governments. Emerging industries cover “internet plus”, new energy, new materials, intelligent manufacturing, cultural creativity, new-generation information technology, energy-saving services, low-carbon services and so on (Changsha.gov, 2019).

Moreover, a low-carbon industrial structure with mutual support will be the advantage of cities in the future. For example, Shenzhen plans to integrate modern finance, modern logistics, network information, service outsourcing, business exhibition and other modern service industries. Eventually, these industries form a mutually supportive and low-carbon industrial structure with high-tech industries and modern service industries (Shenzhen DRC, 2013).

### 4.1.6. Technology applications

In the process of low carbon city development in China, technology applications have been considered seriously by the government at all levels. The technology promotion mechanism and synergy mechanism are critical facilitators for technology application.

Usually, the technology promotion mechanism of low-carbon cities determines the technology application ability. Meanwhile, the technology promotion mechanism can be further implemented through the establishment of technology platforms. According to the trend of technology platform development, it is necessary to promote multicategory information technology and data analysis technology (Gao et al., 2022). On this basis, the big data and information processing capabilities of the city are promoted and applied to multiple stakeholders (Jinan.gov, 2018). For example, based on the technology promotion mechanism, the carbon emission database of each industry and enterprise is applied in combination with the cloud platform and “Internet of Things”.

In addition, the technology synergy mechanism forms a mode of “industry-university-research cooperation” with multiple stakeholders, such as governments, enterprises and research institutions (Ningbo DRC, 2018). On the one hand, enterprises are encouraged to apply for national key low-carbon technologies and products to improve their industrialization capabilities. On the other hand, technologies and products with emission reduction effects are supported by all stakeholders to reach large-scale production and wide application (Jinan.gov, 2018).

### 4.1.7. Assessment mechanisms

In China, although the target control of the current government work is reflected in the indicator system, the emission reduction targets need to be further integrated into the government’s implementation effects. Therefore, an assessment mechanism has arisen for carbon emission practices. The assessment mechanisms can be divided into target assessment and performance assessment. First, target assessment is used to clarify the carbon emission reduction target of each district according to low carbon city programming. Then, the carbon intensity assessment system of each district needs to be established. For instance, Jinan has proposed that the carbon emission intensity reduction index of each district ranges from 20% to 22%, so Huiyin District decreased by 20%, Shizhong District decreased by 20.5%, Zhangqiu District decreased by 21% and Licheng District decreased by 22% (Jinan.gov, 2018). Second, the purpose of the performance assessment is to mobilize the city’s departments. In particular, it is necessary to assess the decomposition objectives of the low-carbon city pilot projects of various departments to

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**Table 4. Indicator system for low-carbon city programming.**

| First level indicators | Second level indicators | Indicator types |
|------------------------|-------------------------|-----------------|
| Urban environment      | ● Forest coverage       | Constrained     |
|                        | ● Greenery coverage in built-up areas | Constrained     |
|                        | ● Annual average PM2.5 concentration | Constrained     |
| Transport & Infrastructure | ● Proportion of public transport trips | Anticipatory     |
|                        | ● Proportion of low carbon energy vehicles | Anticipatory     |
|                        | ● Green Construction proportion of new buildings | Constrained     |
|                        | ● Proportion of energy efficiency retrofits in existing buildings | Constrained     |
| Energy utilization     | ● Nonfossil proportion of primary energy consumption | Constrained     |
|                        | ● Proportion of electricity from renewable sources | Anticipatory     |
|                        | ● Energy consumption reduction rate of key enterprises | Anticipatory     |
| Social environment     | ● Number of low carbon demonstration communities | Anticipatory     |
|                        | ● Household waste separation coverage in residential areas | Anticipatory     |
|                        | ● Carbon emissions per capita | Anticipatory     |
| Industry & Economy     | ● Value added of services as a proportion of GDP | Anticipatory     |
|                        | ● Proportional reduction in CO2 emissions per unit of GDP | Constrained     |
|                        | ● Share of tertiary sector value added | Anticipatory     |

Note: Sourced from the 15 low-carbon cities programming and compiled by the authors.
implement the major goals through the minor objectives. Finally, the pilot practice of low-carbon cities should be effectively promoted by performance assessment (Changsha.gov, 2019).

4.1.8. Collaborative-management mechanisms

China’s local governments need the coordination of various government departments when they face critical issues. Therefore, collaborative management mechanisms have emerged. On the one hand, the critical aspect of comanagement is to clarify the responsibilities of various departments in the city. On the other hand, the implementation of management measures needs to determine the leading departments and cooperation departments to form a strong joint force to promote low-carbon development. For example, the leading department of pollution control and ecological restoration is the Municipal Environmental Protection Bureau. Meanwhile, for the development of urban low-carbon logistics, the leading department is the Municipal Transportation Bureau. The cooperation departments are the municipal development and Reform Commission, the Municipal Economic and Information Commission, and the district governments (Zhuzhou.gov, 2018). In fact, the cross-sectoral coordination mechanism is the core mechanism of low carbon development. It can lead to collaborative decision-making, financial flows, information sharing, citizen participation, and public opinion monitoring (Qingdao DRC, 2014).

4.2. Micro level

4.2.1. Pilot projects of urban spatial layout

In China, the urban low-carbon spatial layout focuses on promoting the compact development of urban space with low-carbon concepts. China’s local governments have implemented three types of pilot projects. The first is the economical use of land for new projects. New project sites need to be strictly approved and must follow the principle of industrial clustering (Shenzhen DRC, 2013). Second, urban renewal includes the demolition and renovation of various projects. Low carbon ecological concepts and technologies are the key promotion of government departments in urban renewal and renovation (Xiamen DRC, 2012). The third aspect is promoting the transformation of the urban structure to a polycentric and cluster structure through rational urban programming. A compact spatial pattern is created to promote a balance between housing and employment and to avoid large-scale and long-distance commuting trips (Hefei DRC, 2019). Ultimately, the goals of reducing urban carbon emissions are achieved through a rational layout of the urban spatial structure.

4.2.2. Pilot projects of city construction

In recent years, China has made many achievements in city construction. Using pilot projects to guide the construction of low-carbon cities is also a key task of local governments.

First, in low-carbon building demonstrations, the energy-saving retrofitting of existing buildings, green building promotion and building energy management are three important aspects (Guilin DRC, 2017; Shenzhen DRC, 2013). Both the central city and its surroundings carry out demonstrations of energy-saving retrofitting for air conditioning, ventilation, lighting, hot water and other energy-using systems (Liuzhou.gov, 2019). Second, green transport pilot projects are proposed to form a convenient transportation network connecting urban and rural areas (Changsha.gov, 2019). As a result, a seamless interchange of transport modes is promoted. Third, commercial pilot projects propose selecting representative stores, hotels, restaurants, tourist attractions and other projects to promote low-carbon technologies. Meanwhile, low-carbon logistics pilot projects are proposed as smart logistics parks, logistics public platforms and logistics information technologies (Ningbo DRC, 2018). Fourth, at present, various waste-separation pilot projects guide residents to form a consensus on the separate disposal of domestic waste. Similarly, carbon emissions can be reduced through the establishment of used goods exchange and recycling centres (Yinchuan DRC, 2018).

4.2.3. Pilot projects of low-carbon industrial parks

In China, in terms of different policy objectives, industrial park pilot projects can be divided into various types, such as green ecological pilot projects, low-carbon agricultural pilot projects, ecological tourism pilot projects, ecological habitat and modern service industry pilot projects (Suzhou.gov, 2014; Nanchang.gov, 2018). Furthermore, a multilevel energy control and energy service platform with a “carbon unit” has been built and demonstrated at various park scales, such as low-carbon residential areas, low-carbon campuses, low-carbon hospitals, and low-carbon car parks. All around low carbon is formed by the guidance on energy use, consumption, and travel at the industrial park level (Liuzhou.gov, 2019; Zhuzhou.gov, 2018). In addition, innovation in technology and management are the main elements of the pilot projects of industrial parks. The details are shown in Table 5.

4.2.4. Pilot projects of management mechanisms

China’s pilot projects of management mechanisms are in line with the current status of low-carbon city management and cover three aspects: (1) carbon emissions monitoring mechanism; (2) carbon emissions trading mechanism; and (3) long-term mechanism of emission reduction.

Table 5. Types and contents of pilot projects for low-carbon industrial parks.

| Types | Demonstration contents |
|-------|------------------------|
| National high-tech development parks | Low carbon high-tech service industries of clustering effect. |
| | Low carbon high-tech service industries of significant policy-support. |
| | High-level research and consulting service institutions for low carbon development. |
| Petrochemical economic-tech development parks | Recycling demonstration pilot in national-level park. |
| | Low-carbon transformation of key energy-using industries such as petrochemicals and chemicals. |
| Logistics demonstration parks | Low-carbon logistics demonstrations. |
| | Information technology for logistics enterprises. |
| | Application of new technologies in smart logistics. |
| Industrial clusters parks | The development of energy conservation and environmental services. |
| | Low-carbon demonstration industry with scale and agglomeration characteristics. |
| | Equipment manufacturing, energy conservation and environmental protection and other strategic emerging industries. |
| Low-carbon industrial demonstration parks | Low-carbon infrastructure development. |
| | Low-carbon management innovation models. |
| | The international advanced level of low carbon industrial. |
| | Low-carbon technology innovation and application models. |
| | Low-carbon industrial model with international cooperation. |
| | Low-carbon industrial chain integrating petrochemicals, steel, automobiles and shipbuilding. |

Note: Sourced from Ningbo DRC (2018), Changsha.gov (2019), Yinchuan DRC (2018), Nanchang.gov (2018) and compiled by the authors.
First, the greenhouse gas data of key enterprises and industrial parks need to be integrated and reported. Therefore, pilot information platforms for carbon asset management should be established, and the big data tracking mode of carbon emissions should be studied (Liuzhou.gov, 2019).

Second, with many cities joining the construction of a national carbon emissions trading market, the carbon emission trading pilot mechanism guides enterprises to carry out emission reduction project declarations and emission reduction trading activities. In accordance with the relevant management measures for carbon emissions trading, governments need to carry out multiple demonstration projects, such as achieving carbon emissions verification for key enterprises, allocating carbon emissions allowances and cultivating third-party verification agencies (Xiamen DRC, 2012; Liuzhou.gov, 2019).

Third, exploring long-term and market-based emission reduction mechanisms mainly includes a pilot of energy price system reform and a green finance pilot. Based on energy price system reform, the reversal mechanism of output per unit of energy consumption was reinforced, and differential tariffs for industries were implemented, such as foundries. Similarly, green finance pilots can encourage eligible enterprises to go public and issue nonfinancial corporate debt financing instruments, corporate bonds and other ways to increase support for emission reduction projects (Ningbo DRC, 2018).

Based on the above three types of pilot measures, some pilot cities have proposed their extended and innovative measures, as shown in Table 6.

### 4.2.5. Pilot projects of low-carbon enterprises

On the one hand, for Chinese local governments, the pilot projects of low-carbon enterprises are mainly to choose enterprises with advantageous technologies to share their experience at the technical level, such as rail transportation, power electronic devices, biomedicine, food processing, cement and building materials, metallurgy and paper making. On the other hand, the experiences of management level can be found in carbon asset management, enterprise technology management, enterprise resource recycling management and low carbon organizational management (Zhuzhou.gov, 2018). Therefore, the promotion of pilot projects in industrial enterprises is a critical issue that governments must be concerned about. The key experiences to be promoted include new technologies, techniques, equipment, products, contract models and management models (Xiamen DRC, 2012).

### 4.2.6. Pilot projects of ecological restoration

The pilot projects of ecological restoration include four aspects: (1) ecological red line delineation; (2) ecological restoration; (3) pollution prevention and control; and (4) carbon sink projects. First, the ecological red line can form ecological barriers and promote the construction of biodiversity in ecological function areas. Therefore, the ecological red line of the city should be strictly delineated. The key management objects of the red line include ecological function areas and woodland wetlands. Meanwhile, the key ecological function protection objectives include soil and water conservation, air purification, flood prevention and disaster prevention (Gulin DRC, 2017). Second, the targets of urban ecological restoration

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**Table 6. List of management innovations of pilot cities.**

| Innovative fields | Innovation measures | Pilot cities |
|-------------------|---------------------|--------------|
| Innovation in carbon emissions monitoring mechanism | ● Establishing a collaborative cross-sectoral carbon data management system. | Liuzhou |
|                   | ● Establishing a regular working mechanism for greenhouse gas data inventory preparation. |  |
|                   | ● Establishing the emissions data management systems. | Hefei |
|                   | ● Exploring low carbon product and technology promotion systems from emissions data. |  |
|                   | ● Promoting a total carbon emission control system. | Jinan |
|                   | ● Exploring a carbon evaluation system for major projects. |  |
| Innovation in carbon emissions trading | ● Innovation in low carbon finance models. | Changsha |
|                   | ● Establishing a carbon credit system. |  |
|                   | ● Reform of the investment and financing system. | Nanchang |
|                   | ● Building a diversified financial input mechanism for low-carbon development. |  |
|                   | ● Market-based deployment reform. |  |
|                   | ● Promoting financial innovation based on carbon emissions trading. | Yinchuan |
|                   | ● Establishing a carbon emissions verification mechanism. | Suzhou |
|                   | ● Promoting low carbon product certification schemes. |  |
| Innovation in long-term mechanism | ● Establishing a long-term programming system of low-carbon development. | Gongqingcheng |
|                   | ● Piloting the carbon emission assessment of urban programming. |  |
|                   | ● Establishing a low carbon industry mechanism. | Ankang |
|                   | ● Promoting an ecological compensation mechanism for carbon sinks. |  |

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**Table 7. Key technology types and innovation content.**

| Key technologies | Innovation fields |
|------------------|------------------|
| ● Energy-saving technologies | ● Energy-saving technologies for high energy consumption areas such as electricity, building materials, transport and construction. |
|                   | ● Energy-saving technologies for electrical and mechanical products. |
|                   | ● Commercial and residential energy efficiency technologies. |
|                   | ● Stepping use technologies of energy. |
| ● Renewable energy technologies | ● Development and utilization technologies of fuel cell, hydropower, biomass, hydrogen, geothermal, ocean energy and biogas. |
|                   | ● Low-cost, large-scale renewable energy development and utilization technologies. |
|                   | ● Solar power and solar building integration technologies. |
| ● CO2 capture, utilization and storage technologies | ● Tracking and exploring carbon dioxide capture technologies for precombustion, postcombustion and oxygen-enriched combustion. |
|                   | ● Underground and seawater carbon sequestration technologies. |
|                   | ● Post-capture carbon transport technology. |
| ● Carbon sequestration technologies | ● Forestry and other types of carbon sequestration engineering. |
|                   | ● Technology of enhancing the effects of carbon sequestration. |
|                   | ● Technology of enhancing forest carbon sink capacity. |

*Note: Sourced from the Jinan.gov (2018), Shenzhen DRC (2013), Nanchang.gov (2018), Ningbo DRC (2018), Yinchuan DRC (2018), and compiled by the authors.*
projects are to protect national and regional nature reserves, forest parks, geological parks, wetland parks and other ecologically fragile areas (Hefei DRC, 2019). Ultimately, it can improve the resilience of urban ecosystems, especially facing extreme weather. Third, pollution prevention and control should focus on the improvement of environmental quality. In particular, pilot projects need to cover the related indicators of air, water and soil, such as the urban household waste disposal rate, urban sewage treatment rate and other related indicators (Guilin DRC, 2017). Fourth, carbon sink projects should be constructed in areas with suitable urban conditions, and carbon sink resources need to be developed and stockpiled. In addition, a suitable carbon sink measurement and monitoring and assessment system should be established (Ankang.gov, 2018; Changsha.gov, 2019).

4.2.7. Pilot projects of energy optimization

From the current objectives of low carbon city programming, the first thing that needs to be done is the improvement of energy efficiency. The pilot of industrial energy efficiency promotion, the management pilot of key energy-using enterprises and the energy regulation pilot of industrial enterprises are all important initiatives for energy efficiency promotion (Liuzhou.gov, 2019).

From the perspective of long-term development, both energy-saving and energy mix optimization are important demonstration projects. On the one hand, it is necessary to improve the energy-saving assessment and eliminate technologies, processes and equipment with energy-waste characteristics. Moreover, the launch of high energy-consuming and high-emission projects must be strictly controlled following the review system of investment projects or another (Gongqingcheng Gov, 2018). On the other hand, in the field of new energy projects in cities, the focus should be on promoting the construction of large-scale photovoltaic power generation projects and wind power projects. Meanwhile, straw power, biogas power and geothermal power can be developed according to local conditions (Zhao et al., 2016; Hefei DRC, 2019). As a result, a number of innovative technical measures were generated in pilot projects. The relevant technical fields are shown in Table 7.

4.2.8. Pilot projects of low-carbon lifestyle

A low-carbon lifestyle in cities requires raising the low-carbon awareness of the public. Therefore, low-carbon lifestyles and consumption patterns should be promoted as a conscious behaviour of citizens (Qingdao DRC, 2014). First, low-carbon behaviours should be developed, for example, low-carbon travel by fostering the use of public transport and community activities such as “car-free days” and low-carbon shopping by refusing to overpackage goods and fostering the concept of frugal consumption. Second, we should actively promote waste separation and improve the renovation of waste separation and recycling facilities in public areas to achieve wider coverage. Furthermore, urban communities can encourage the selection of “energy-saving communities” and “energy-saving households” by creating a number of green communities with exemplary features (Suzhou.gov, 2014).

5. Discussion

A low-carbon city is not only a vision but should also focus on practice. The pilot city with specialized programming we studied is not only a blueprint of the city future but also the first step that needs to be taken to develop a low-carbon city. With the background of China’s “carbon neutralization” by 2060, low-carbon development practice is essential (MEE, 2021a). The driving model for low-carbon practices is shown in Figure 4. According to our research of policy systems from macro to micro, the following key issues must be addressed in low-carbon pilot practice.

First, only 15 of 87 provinces and cities have promulgated special programming, so the low-carbon planning guidance rate is low. In China, traditional policies pay more attention to urban spatial planning and construction from a macro perspective, but the practice of emission reduction is insufficient. Furthermore, the factors of renewable energy utilization, building energy conservation, and garbage disposal were not brought to the forefront in traditional planning. Therefore, as a new programming model, low-carbon programming has great potential for application, and future research can focus on various aspects, such as policy structure and implementation efficiency.

Second, compared with traditional planning, low-carbon programming pays more attention to low-carbon practices. For example, an indicator system of city master planning includes four main categories, namely, economy, society, resources, and environment (Stanley, 2008). However, in the process of urban low-carbon development, the above
four categories appear too macro. More detailed factors need attention at the micro level (APEC, 2011), such as building energy savings, ecological restoration, carbon emissions trading (MEE, 2021b), energy optimization and low-carbon lifestyles (Xinhua News Agency, 2020). Therefore, to combine traditional planning with low-carbon programming, it is necessary to establish the corresponding indicator system to ensure that the macro indicators are decomposed layer by layer to facilitate implementation.

Third, how to break through the existing environmental constraints needs profound consideration. As we know, the planning and construction of low carbon cities is not carried out on a blank sheet of paper but on the basis of existing cities. Therefore, pilot projects at the micro level are very important. On the one hand, as targets practice of low-carbon city planning, a set of low-carbon development models that meet the reality of the city should be explored through pilot projects and supported in terms of policies, projects, funds and technologies to ensure that the implementation is put into practice. On the other hand, local governments should have different innovative pilot projects to deal with different environmental situations. For a controllable environment, we should reduce carbon emissions through target guidance, indicator constraints, and economic and technical measures. For uncontrollable environments, we should also actively respond through innovation and pilot projects to reduce ecological damage.

In summary, the key issues that must be solved in pilot practice are closely related to 16 factors we studied from macro to micro. These factors can also be applied to other policy practices, such as low-carbon guidance documents and city master plans (Baoding Gov, 2019; Shanghai Gov, 2017). In addition, in the process of promulgating low-carbon programming, to ensure its practicality, the collision of the planning system, regulatory system and existing environmental constraints must be researched from multiple dimensions. Similarly, the complementary and exclusive aspects with other policies need to be critically studied.

6. Conclusions

As the largest developing country, China has recognized the importance of low-carbon cities. To date, three batches of 87 low-carbon pilot provinces and cities have been presented by the Chinese government. To investigate how policy interventions facilitate low-carbon pilot development, existing policies promulgated by 87 local governments were examined from 2010 to 2021. This study found that special programming policies play an effective role in guiding the development of low-carbon pilot cities. Therefore, a total of 15 cities that issued special programming were identified. This paper adopted a qualitative approach to form a framework of the factors influencing the development of low-carbon pilot projects. This research highlighted 16 factors at two levels, i.e., macro level and micro level.

From a macro perspective, the type of low carbon city is determined by the city’s positioning. Similarly, the carbon emission target is determined by the type and positioning of a city. Furthermore, a multilevel indicator system has a constraining effect on the low-carbon guidance of various factors led by emission targets. Based on positioning, targets and indicators, the effective development of low-carbon cities is ensured in macro aspects such as economy, industry, technology, management, and assessment.

From a micro perspective, a total of 8 types of demonstration projects are proposed by 15 cities. The diversity of pilot project types ensures that the project implementation covers multiple factors of cities. In terms of a city, the pilot projects selected can be one or more of the 8 types of pilot projects to achieve the emission reduction target. Therefore, we have identified a pilot project system. The practical effects of the project can promote macro policy synergy and innovation.

This study offers a comprehensive analysis of China’s programming policies related to low-carbon pilot cities. These findings help to understand the development landscape of pilot low-carbon cities in China. This provides useful inputs for low-carbon city development in other countries.

Due to the low promulgation rate of low-carbon special programming of local governments, the limitation of this study belongs to its research scope. Further research opportunities exist to conduct in-depth investigation of synergistic effect of policy interaction, and to study how to facilitate the policy updating. In addition, the strategies and differences are worth to investigate between the national and local governments in China. Similarly, various quantitative analysis approaches can be applied in policy effect evaluation, such as difference-in-differences model.

Declarations

Author contribution statement

Lei Gao: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Zhen-Yu Zhao; Lei Gao: Conceived and designed the experiments. Wrote the paper.
Cui Li: Performed the experiments; Analyzed and interpreted the data.
Cong Wang: Contributed reagents, materials, analysis tools or data.

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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