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Review

Development and Challenges of Low-Carbon Cities in China: Current Situation, Influencing Factors, and Sustainability Strategies

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Abstract: As global climate change becomes increasingly severe, low-carbon city construction has emerged as a critical strategy to address this challenge. This study explores the concept, current development status, and challenges of low-carbon cities, focusing on the progress and issues in China's low-carbon city construction. The research covers defining low-carbon cities, their background, policy impacts, and analysis of practical cases. Specifically, the research focuses on identifying the challenges faced in the development of low-carbon cities in China and proposing strategies to effectively address these obstacles. Findings suggest that difficulties, such as regional disparities, inconsistencies in policy implementation, and technological barriers, hinder progress. By synthesizing insights from previous studies, this paper proposes actionable strategies, including strengthening policy frameworks for consistent application, leveraging smart technologies for efficient energy and resource management, and fostering public engagement through targeted education. These recommendations provide a guideline for future research and practical actions, contributing to sustainable urban development and offering insights for policymakers and urban planners.

Keywords: low-carbon cities; carbon emissions; environmental policy; building energy efficiency; life cycle assessment (LCA); energy structure; sustainability

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1. Introduction

Low-carbon cities represent an innovative urban development model that aims to minimize greenhouse gas emissions while maintaining economic growth and quality of life. These cities are characterized by efficient energy use, optimized industrial structures, and integrated sustainable development approaches. China's significant progress in low-carbon city construction in recent years has become a crucial part of global efforts to combat climate change while advancing urban modernization. Since the 21st century, academia, international organizations, and various levels of government have been exploring "low-carbon cities", aiming to optimize energy structure, improve energy efficiency, and reduce greenhouse gas emissions to promote green growth and ensure the sustainability of the ecological environment [1,2]. Achieving low-carbon cities involves carbon reduction in specific areas such as energy, transportation, and buildings, emphasizing the important roles of policies, technology, management, and public participation [3]. Aligned with the goals of low-carbon city development, the construction of smart cities leverages information technology and data management to further support China's transition to a low-carbon economy.

As a developing country undergoing rapid urbanization and industrialization, China is responsible for reducing urban carbon emissions [4,5]. In 2010, China launched low-carbon province and city pilot projects, which not only accumulated valuable experience, but also highlighted synergies between low-carbon city initiatives and smart city development. By leveraging technologies like the Internet of Things (IoT), Complex Network Analysis (CNA), and Smart Energy Management (SEM), these projects demonstrated how resource optimization and energy efficiency can support carbon reduction goals. The development of low-carbon and smart cities in China has evolved through distinct phases, including pilot demonstrations (2010–2015) and comprehensive promotion (2015–2020), emphasizing policy innovation, technological advancements, and international collaboration [3,6–8]. Despite progress, as urbanization accelerates, China still faces complexities in controlling carbon emissions and advancing smart city construction toward low-carbon city development, necessitating robust policy guidance, legal protection, and an improved regulatory framework [9–11].

There are numerous studies reviewing the development of China's low-carbon cities. Yan, Y. (2022) highlighted that China's low-carbon city construction has progressed from its initial conceptualization to the implementation of three batches of pilot projects, demonstrating a shift from isolated city-level initiatives to broader integration at the family, community, and urban cluster scales [12]. Jiang, W. and Kang, W.M. (2019) indicated that research on low-carbon cities in China has shifted from macro-level conceptual studies to micro-level specific issue analyses of the spatial scale of research and evaluation systems [7]. Cai, W.G. et al. (2009) summarized improvements in building energy efficiency, driven by policies targeting energy consumption in low-efficiency buildings, promoting renewable energy, and establishing mandatory energy standards for public buildings [13]. Wu, Y. et al. (2022) explored the interplay between public awareness and behavior in adopting low-carbon lifestyles, underscoring the importance of societal engagement in achieving sustainable urban development [14].

However, despite these advancements, several shortcomings persist in China's low-carbon city construction. Firstly, there is a lack of micro-level research on low-carbon city construction and comprehensive assessments of carbon reduction measures' effectiveness. Second, a gap persists between policy and technology in practical applications, as many low-carbon technologies face bottlenecks due to ineffective implementation mechanisms. Additionally, public understanding of low-carbon concepts has not fully translated into actual behavior, with insufficient public participation hindering progress in low-carbon city construction [12].

Previous studies have largely focused on specific aspects of low-carbon development, such as the carbon consumption associated with the production of building materials, their adaptation to various climatic regions to achieve low-carbon goals, and policy recommendations for reducing carbon emissions in building processes [15,16]. However, these efforts often lack a macro-level perspective, concentrating primarily on regional case studies rather than offering a comprehensive national overview. This study addresses this gap by synthesizing findings from various regional reviews to develop a holistic understanding of low-carbon city development across China.

To address existing gaps in the field, this study introduces a new theoretical perspective through a comprehensive analysis of key challenges and solutions in low-carbon city development. By integrating findings from diverse research studies, this perspective identifies recurring patterns and core issues, offering a structured framework to understand the progress, obstacles, and opportunities in this field. The primary research questions guiding this review are as follows: "What are the challenges encountered in developing low-carbon cities in China, and what strategies can be proposed to overcome these challenges?". The hypothesis posits that difficulties stem from regional differences, inconsistent policy implementation, and technological barriers. Unlike conventional reviews, this approach not only consolidates existing knowledge but also provides actionable insights and strategic directions to bridge the gap between academic research and practical implementation.

This review synthesizes the existing literature to outline the current state of low-carbon city development in China, explore the main factors influencing urban carbon emissions, and evaluate existing methods and strategies for reducing urban carbon emissions. The research aims to examine and identify barriers to effective policy implementation and technology integration, helping to develop recommendations to improve the alignment between policy frameworks and practical technology integration. By analyzing the development intentions of "low-carbon cities", this study clarifies the roles of various stakeholders, outlining actionable strategies that all parties should advocate or adopt to support low-carbon city development. Furthermore, it highlights existing gaps and provides a roadmap for future research and practice, paving the way for more efficient and effective solutions in achieving low-carbon goals.

This review synthesizes the literature to examine the current state of low-carbon city development in China, analyze the factors influencing urban carbon emissions, and evaluate existing methods and strategies for emission reduction. It identifies barriers to effective policy implementation and technology integration, offering recommendations to enhance alignment between policy frameworks and practical applications. By examining the developmental intentions of "low-carbon cities", the study clarifies the roles of various stakeholders and proposes actionable strategies to support low-carbon city initiatives. Furthermore, the study emphasizes the necessity of a tailored, context-specific approach to low-carbon city development. It highlights how current research often focuses on regional factors, but lacks a comprehensive national synthesis that aligns local insights with overarching strategies. By integrating findings from different regions, this review provides a macro perspective on aligning regional capabilities with customized solutions. It underscores the importance of understanding regional contributions, drawing lessons from diverse contexts, and formulating strategies suited to specific circumstances.

The findings contribute to existing knowledge by identifying barriers to policy implementation, clarifying stakeholder roles, and offering a structured roadmap for future research and practice. By bridging the gap between fragmented regional studies and cohesive national strategies, this review delivers actionable insights and practical recommendations to policymakers and practitioners, paving the way for more effective and scalable solutions to achieve low-carbon development goals.

2. Review Methods and Framework

This paper searched Web of Science, Science Direct, CNKI, and other databases to study low-carbon urban development and urban carbon emission indicators in China. During the initial review phase, the paper focused on research and conference papers from the past 15 years, with the keywords "low-carbon city" and "low-carbon society in China", covering fields such as architecture, urban planning, engineering, environment, energy, and algorithms. The search was conducted on publications from the past 15 years, yielding a total of 3409 related documents (Web of Science = 486, Science Direct = 1507, CNKI = 1416). Removing 2222 duplicated articles, from the remaining 1185 articles, 233 SCI and EI papers meeting the criteria were selected. Further screening based on top journals (SCI Q1) and top conference papers (EI) resulted in 125 documents that met the requirements. The content and research methods of these 125 papers were then thoroughly analyzed, excluding those not closely related to "Low-carbon city and Low-carbon Society in China". Ultimately, 75 papers were selected for detailed analysis and review, including 57 research articles and 18 review articles (as shown in Figure 1) [17].

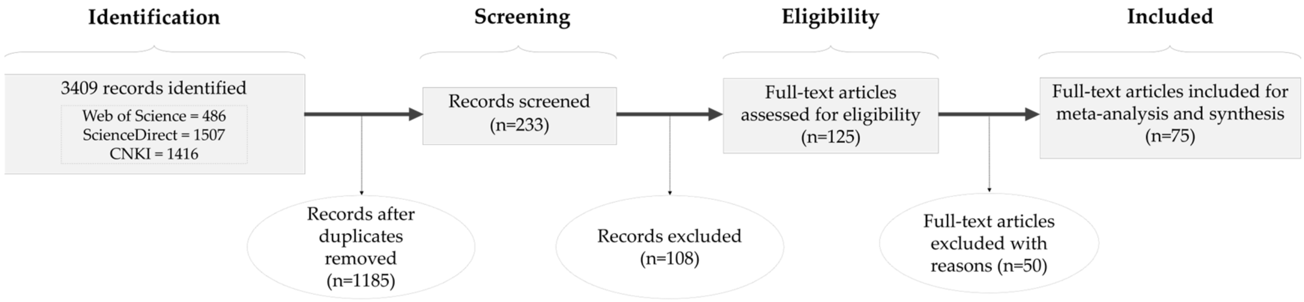

Figure 1. The screening process of the literature.

We summarized the research content of these 75 papers. We concluded that the current research on low-carbon cities and carbon emissions in China mainly focuses on four aspects: the current development status of low-carbon cities, factors influencing urban carbon emissions, methods for accounting for urban carbon emission indicators, and methods for reducing urban carbon emissions. The literature content framework, covering the four aspects, is presented as follows:

1. The development of low-carbon cities in China involves addressing several critical questions. Initially, by examining low-carbon city policies and national policies, what are the major challenges encountered in advancing low-carbon cities, and how do regional differences necessitate distinct development strategies? Additionally, how do China's Low-Carbon City Pilot (LCCP) policies influence urban development? This section also explores the implementation of building energy efficiency standards, regulatory enforcement, and certification systems introduced by the Chinese government to promote energy conservation. Finally, it examines the current status of low-carbon city development and evaluates the effectiveness of LCCP policies through detailed reviews.
2. The factors influencing urban carbon emissions are explored through various dimensions. The impact of compact city design on emissions is assessed, alongside three approaches to building materials that can lower emissions. The relationship between rapid economic growth, economic output, energy intensity, and carbon emissions is analyzed. The influence of energy type and quality, as well as governmental policies and their effectiveness based on income levels, is discussed. The role of macro-control over population density and public awareness in guiding low-carbon behaviors is also highlighted.
3. Methods for calculating urban carbon emission indices focus on three key approaches: a low-carbon city evaluation system that identifies contributing factors to carbon dioxide emissions; life cycle assessment for reducing emissions across operational, material selection, and construction stages; and space–time simulation to provide insights into macro-level dynamics for effective macro-control.
4. Lastly, the section on urban carbon reduction approaches investigates two main strategies. The first involves establishing a low-carbon city model with policy recommendations for different stages (input, transition, output) and integrating low-carbon building design with life cycle assessment to evaluate and reduce greenhouse gas emissions.

Figure 2 illustrates a detailed content framework of this literature review, making reference to the contents above.

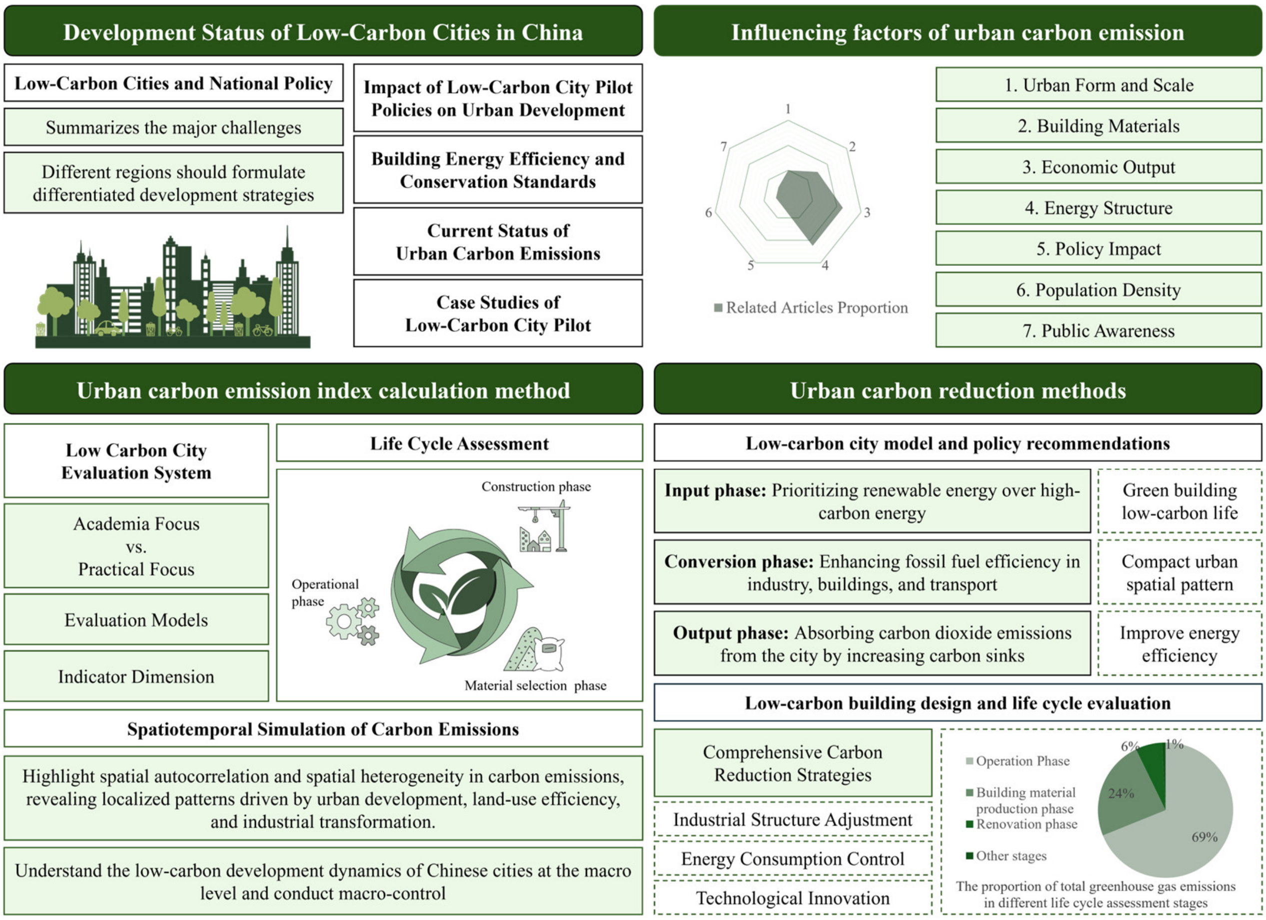

Figure 2. The framework of the literature review.

3. Development Status of Low-Carbon Cities in China

The development status of low-carbon cities in China reflects a comprehensive journey from policy inception to practical application. Initially, national policies have set the stage for low-carbon urban development by emphasizing technological and structural advancements. Building on these policies, Low-Carbon City Pilot (LCCP) initiatives have driven green technology innovation and enhanced urban sustainability, while improved energy efficiency standards aim to optimize energy use across different climate zones. Analyzing current urban carbon emissions reveals shifts in sectoral contributions and regional disparities, highlighting ongoing challenges and the need for better data infrastructure. Finally, case studies of LCCP cities demonstrate the practical outcomes and effectiveness of these initiatives in achieving low-carbon goals, offering insights for future development.

3.1. Low-Carbon Cities and National Policy

The core goal of low-carbon cities is to reduce carbon emissions and increase carbon sinks. Policies promote low-carbon development through technological effects and structural effects [18]. For example, Shenzhen intends to become China's first low-carbon eco-pilot city, while Baoding aims to be a solar-friendly city; both have been selected for low-carbon city pilot projects [19]. However, various issues arise in practice, such as a lack of clear definitions, standards, and goals for low-carbon cities; and an overemphasis on technology and economic development, which often leads to neglecting environmental objectives. Furthermore, the current government's performance evaluation mechanism compels local governments to prioritize urban development at the expense of environmental protection.

The impact of low-carbon city policies varies with the scale of cities. In large cities, due to agglomeration effects, low-carbon construction significantly enhances green total factor productivity. Eastern regions contribute more to carbon reduction due to higher economic development, urbanization rates, and greater openness. In contrast, western regions, lacking advanced technology, talent, and adequate infrastructure, face higher environmental costs and greater pressure for industrial transformation. This results in higher variance and uncertainty in their carbon reduction efforts. These regional disparities risk economic imbalances and complicate national low-carbon goals, making it crucial to balance regional differences for policy effectiveness [18].

3.2. Impact of Low-Carbon City Pilot (LCCP) Policies on Urban Development in China

According to the data analysis of 277 prefecture-level cities from 2007 to 2020, it was identified that LCCP construction drives urban green development through green technology innovation [20]. Research indicates that LCCP policies significantly enhance the green total factor productivity of pilot cities [21]. They also help to reduce urban PM2.5 concentrations, showing spatial spillover effects [22].

Since 2010, China has implemented LCCPs in three major phases, showing distinct characteristics and progressive policy evolution.

The initial batch of eight cities, including Tianjin, focused on developing foundational low-carbon plans and green development programs. These pilot cities demonstrated significant improvements in green technology innovation and urban PM2.5 reduction, with effects becoming noticeable after 2–3 years of implementation [22].

The expansion to 29 cities, including Beijing, emphasized establishing target responsibility systems. This phase showed enhanced policy effectiveness through stricter emission reduction targets and assessment mechanisms [22]. The policy significantly improved green total factor productivity and ecological efficiency through promoting technological innovation [23].

The inclusion of 45 additional cities featured strengthened requirements for industrial innovations and technological advances [22]. This phase demonstrated marked improvements in carbon emission efficiency and air quality, with pilot cities achieving an 18.0-point increase in their Energy Transition Index, compared to 7.9 in non-pilot cities [23].

Through systematic implementation and progressive enhancement, LCCPs have effectively driven urban green development, while optimizing industrial structures and environmental performance through technology research, development subsidies, and tax incentives [23].

3.3. Building Energy Efficiency and Conservation Standards

To achieve urban carbon emission reductions, China has promoted building energy conservation through policies such as building energy consumption (BEC) constraint policies. Building energy consumption currently accounts for over 25% of total national energy consumption, and this is expected to increase to 35% by 2020, making buildings responsible for around 18% of energy-related carbon dioxide emissions in China [24].

China has established a sophisticated urban building energy conservation standard system that incorporates international assessments. These standards specify energy-efficient design requirements, including the following thermal performance criteria: an exterior wall U-value not exceeding 1.0 $W/(m^2K)$, a roof U-value not exceeding 0.7 $W/(m^2K)$, and window-to-wall ratio limits of 70%. For buildings with window-to-wall ratios below 40%, visible light transmittance must be at least 0.4 [24].

These standards incorporate international assessments, specifying energy-efficient design, monitoring, and applicability to different climate zones [25]. Despite the comprehensive nature of these standards, they did not initially have the desired effect. Early implementation faced challenges—a 2005 survey showed that only 58.53% of projects were designed according to energy efficiency standards, with just 23.25% constructed to meet them. Enhanced regulatory measures from 2005 to 2007 dramatically improved compliance rates: designed projects rose to 97% and constructed ones to 71% [13].

China has also established a building energy certification system based on the certification systems of other countries, using five levels to represent building energy efficiency and using energy-saving design standards as benchmarks, promoting sustainable urban development [26]. For instance, for large public buildings, energy consumption monitoring shows they consume 70–300 kWh/m^2, which is 10–20 times that of typical residential buildings [13]. Through systematic implementation of these standards, China aims to reduce building energy consumption by 50% compared to typical buildings from the 1980s [24].

Recent advancements in building technologies have further supported the goals of these standards. The use of high-performance building envelopes, smart building technologies, and sustainable materials has significantly improved thermal performance and reduced operational energy use. The incorporation of renewable energy sources, such as solar photovoltaic systems, into building designs has also reduced reliance on fossil fuels while lowering operational costs.

As China continues its rapid urbanization, enhancing building energy efficiency remains crucial for achieving national carbon reduction goals. Future efforts will likely focus on strengthening enforcement mechanisms to ensure compliance with existing standards, expanding the scope of certification systems to include more building types, promoting research into new materials and technologies that further reduce energy consumption, and increasing public awareness of the benefits of energy-efficient buildings through educational campaigns. By addressing these areas, China aims to further its commitment to low-carbon urban development while fostering a more sustainable built environment [24–26].

3.4. Current Status of Urban Carbon Emissions in China

China's urban carbon emission profiles have shifted notably, with a decrease in industrial carbon emissions, but an increase in emissions from the commercial and transportation sectors. The share of direct coal consumption has declined, whereas the shares of electricity and oil have risen, and the proportion of clean fuels like natural gas has steadily increased [27].

In terms of spatial dimensions, the northeast and north China regions lead in emission reductions, while the southwest shows the highest efficiency [28]. However, overall, the carbon emissions from China's building operations have increased significantly, rising from 0.67 Gt to 2.11 Gt between 2000 and 2018, now accounting for 21.9% of total national emissions. This growth exhibits distinct regional patterns and driving factors that require systematic analysis.

A study has proven that urbanization and economic growth are the main drivers of carbon emissions in China [29]. Despite only accounting for 18% of the national population, 35 major cities contribute 41% of China's GDP and 40% of its commercial energy use and carbon emissions, highlighting regional disparities. Several pilot cities have compiled greenhouse gas emission inventories and explored reduction pathways. However, these inventories are not yet authoritative, and there is a need for China to establish a robust data collection infrastructure to improve the accuracy and availability of carbon emission data.

Urbanization and economic growth are key drivers of carbon emissions in China, with urban energy demand rising as new migrants consume more energy per capita than rural residents [27,28]. Building energy efficiency is crucial, as operational carbon intensity in commercial buildings grew 2.88% annually in 2001–2016. Provinces in northeast and north China led in terms of reductions. Stricter energy standards, such as Shanghai's 65% reduction target for new commercial buildings, significantly lower energy use and support national low-carbon goals [28].

Furthermore, a technological lag in adopting advanced building technologies contributes to slower progress in emission reductions. Many cities still rely on outdated practices that hinder their ability to meet low-carbon targets effectively [2,30,31].

3.5. Case Studies of Low-Carbon City Pilots (LCCPs)

Existing research has evaluated several LCCP cities. For instance, Nanjing City achieved a 55% reduction in carbon emissions per unit of GDP from 2002 to 2009, while Taiyuan City still needs improvement in environmental and energy aspects [32,33]. LCCP policies significantly impact low-carbon city construction, requiring the government to integrate evaluation results, adjust policies, and enhance practical outcomes.

Some cities, like Zhenjiang in Jiangsu province, have established evaluation models and carbon management systems to predict future carbon emission trends and assess carbon footprints across sectors such as agriculture, industry, and transportation [34]. However, many pilot cities face challenges due to technological lag, which limits their ability to implement innovative solutions effectively. This lag can be attributed to insufficient investment in research and development, as well as a lack of collaboration between local governments and technology providers [31].

Multiple studies indicate that LCCP policies significantly enhance the green total factor productivity (GTFP) of pilot cities by means of scientific and technological innovation, optimizing industrial structure, improving energy intensity, and increasing carbon sinks. The policy effect increases over time [35]. To sustain progress, the government should continue investing in low-carbon technologies, while promoting innovation and industrial transformation. Resource-based cities should also set reasonable carbon reduction goals. The implementation and research status of China's urban development under low-carbon city pilot policies is summarized in Table 1.

Table 1. Literature review on implementation of low-carbon city pilot policies in China.

Source	Year	Research Content
Lang S.W. [24]	2004	Energy efficiency standards for residential buildings in north, central, and south China
Hong T.Z. [25]	2009	Comparison and optimization of energy-saving design standards for public buildings
Cai, W.G.; Wu, Y. et al. [13]	2009	China's government strategies and measures to improve building energy efficiency
Dhakal, S. [27]	2009	Analysis of energy and carbon emission impacts in major Chinese cities
Bi, J.; Zhang, R.R. et al. [32]	2011	Methods of urban greenhouse gas emission inventory in China: case study of Nanjing city
Khanna, N.; Fridley, D. et al. [2]	2014	Historical development and pilot planning evaluation of low-carbon cities in China
Lin, B.Q.; Liu, H.X. [29]	2015	Evaluating regional disparities in China's carbon emissions using LMDI model
Wang, Y.; Song, Q. et al. [34]	2015	Pathways to achieving LCCP low-carbon goals: case study of Zhenjiang
Ji, Q.F.; Li, C.C. et al. [19]	2017	Concept and methodology analysis of green city development in China

Table 1. *Cont.*

Source	Year	Research Content
Wei, Z.; Xu, W. et al. [26]	2018	Study on China's city-level building energy use benchmarking model
Cheng, X.H.; Yi, J.H. et al. [18]	2019	Impact analysis of low-carbon city construction on green growth using differential model
Cai, B.F.; Cui, C. et al. [30]	2019	Uncertainty analysis of GHG emission data in Chinese cities
Wang, Y.F.; Li, L.Y. [33]	2019	Low-carbon city evaluation and economic development analysis in Taiyuan
Qiu, S.L.; Wang, Z.L. et al. [35]	2021	Impact of LCCP policies on urban green total factor productivity
Liu, X.; Li, Y.C. et al. [36]	2022	Carbon emission reduction effect and regional impact Analysis of pilot policies of low-carbon cities based on DID model
Li, K.; Ma, M.D. et al. [28]	2022	Carbon reduction assessment and decomposition framework for commercial buildings in China
Chen, M.; Ma, M. et al. [31]	2022	Carbon emission analysis of residential and commercial buildings in China, based on carbon Kuznets curve (CKC) model
Chen W, Liu J et al. [20]	2023	Multidimensional impact analysis of LCCP policies on urban green development
Sun, Y.S.; Zhang, R. et al. [22]	2023	Study on economic, energy, and environmental development in LCCP policies by adopting difference-in-differences (DID)
Ren, Y.; Yang, F. et al. [21]	2024	Study on influence of LCCP policies on urban land green use efficiency
He, Y., Lai, Z. et al. [23]	2024	Analysis of impact and mechanisms of LCCP policies on urban PM2.5 levels

4. Factors Influencing Urban Carbon Emissions

The factors influencing urban carbon emissions demonstrate complex interactions and varying impacts across China's cities. From physical aspects, like urban form, to socioeconomic drivers, such as economic output and public awareness, these factors form an interconnected system that shapes urban carbon trajectories.

4.1. Urban Form and Scale

The spatial form and scale of a city directly affect its carbon emissions. A compact city model, characterized by high density and efficient land use, reduces energy consumption by minimizing transportation distances and improving land use efficiency. This model requires investments in district heating networks, public funding for retrofitting neighborhoods, and the promotion of decentralized renewable energy systems [37]. Beijing, Shanghai, Tianjin, and Guangzhou, as the most developed metropolitan areas in China, were selected for a study examining the relationship between urban form and carbon emissions. A study conducted between 1990 and 2010 concluded that a multi-nuclear urban development pattern, compared to a dispersed one, proved to be more sustainable in terms of resource efficiency and environmental impact. Currently, these cities are taking steps to gradually adopt this compact form to reduce carbon emissions and improve resource efficiency [38]. The optimization of urban form and scale therefore represents a fundamental pathway for achieving low-carbon city goals through improved spatial efficiency.

4.2. Building Materials

Past studies have indicated that energy consumption rises with increased use of building materials, a trend noted in China. For example, in 2015, as the building steel stock, which symbolizes building materials, grew by 1.57 billion tons, energy consumption surged by 604 million tons of standard coal, compared to 264 million tons in 2000, significantly contributing to carbon emissions. The embodied carbon associated with these materials further exacerbates the overall carbon footprint of the building sector [39]. Research indicates that embodied energy can account for a significant portion of a building's total lifecycle energy consumption, with estimates ranging from 20% to 50% for residential buildings in China, depending on various factors such as building type and construction practices [40].

The life cycle assessment (LCA) method serves as an essential tool for evaluating the environmental impact of building materials, while the Structural Decomposition Analysis (SDA) method provides a quantitative analysis of the key driving factors behind the increase in carbon dioxide emissions in China [39,40]. By analyzing both operational energy and embodied energy, these methods facilitate a more comprehensive understanding of a building's overall carbon footprint. Furthermore, the Logarithmic Mean Divisia Index (LMDI) method has emerged as a preferred analytical tool for decomposing carbon emission data, allowing for a clearer understanding of the factors influencing emissions at both the provincial and national levels [39].

A detailed analysis of steel-construction residential buildings in China revealed that the embodied energy from materials such as steel, concrete, and cement constitutes over 60% of total energy consumption in these structures. This finding underscores the need for architects to consider not only the operational efficiency of buildings, but also the environmental impacts associated with material choices during construction.

By understanding the impacts of building materials and their embodied carbon, the LCA method contributes to policy evaluation in building practices and material selection, which is essential for developing effective low-carbon strategies [41]. Improving the efficiency of the use of building materials can reduce emissions in the upstream production sector. The building materials industry should adhere to energy-saving regulations, promote low-carbon technologies, and use green materials and energy-efficient products to lower emissions during construction [39,42].

4.3. Economic Output

Urban economic output is a critical factor in carbon emissions, with income levels closely linked to carbon emissions. From 1997 to 2015, the increase in carbon dioxide emissions mainly came from middle- and high-income countries, with middle- and low-income countries contributing 20% to the global emission increment, and low-income countries contributing almost nothing [43]. Different regions exhibit varying carbon emission trends based on their economic development levels, with the western and central regions of China having higher carbon intensity compared to the eastern and southern regions [44]. Industrial structure plays a significant role in determining emissions, as regions that are heavily reliant on energy-intensive industries tend to experience higher carbon output. In contrast, regions transitioning towards high-tech and service-based industries show reduced emissions per unit of economic output.

Urban carbon emissions are driven by rapid industrialization and economic output growth, which often lead to higher emissions. However, a shift towards more energy-efficient and technology-driven industries can mitigate this effect [45]. The shift in industrial structure, particularly from manufacturing to services, further contributes to lowering carbon emissions. This industrial transformation, combined with the effects of digital finance, can significantly increase carbon productivity (GDP per unit of carbon dioxide emissions), and has spatial spillover effects [46].

Policymakers should prioritize aligning industrial policies with low-carbon objectives, and enhance technological knowledge, aligning economic growth with environmental resources. Targeted policies for high-carbon-intensity regions should be developed alongside incentives for technology-driven industries. Furthermore, digital finance mechanisms—such as green bonds and carbon trading platforms—should be emphasized as vital tools for emission reduction [47].

4.4. Energy Structure

Energy type and quality significantly influence carbon emissions. Although carbon emission intensity has decreased during China's urbanization and industrialization processes, construction activities still rely on fossil fuels [48]. The Energy Transition Index (ETI) evaluates the performance of urban energy systems and their transition readiness. From 2005 to 2015, most Chinese cities improved their ETI scores, but the gap widened; the top 10 cities saw an average ETI score increase of 18.0, while the score of the bottom 10 cities only increased by 7.9. Building energy consumption shows that large public buildings consume 70–300 kWh/m^2, which is 10–20 times that of typical residential buildings [47]. A shift towards cleaner energy sources and improving energy efficiency are essential strategies for reducing emissions, especially in energy-intensive sectors.

Industrial structure also plays a key role in energy consumption. Sectors such as manufacturing and construction tend to consume significantly more energy than the service sector, with building energy consumption rising from 10% in the 1970s, to over 25% of total national energy consumption by 2006 [47]. Tailoring energy structures to regional industrial profiles can help cities to meet low-carbon goals and drive sustainable urban development [49]. The government should encourage innovation in low-carbon technologies, invest in advanced energy solutions, and offer financial incentives for adopting low-carbon technologies to decarbonize industrial processes [50,51].

4.5. Policy Impact

Government environmental policies influence urban development and carbon emissions differently based on income levels. For high income levels, strong environmental policies favor carbon emission reduction, while for low income levels, they can also mitigate the negative impacts of urbanization [52].

By comparing the panel data of 80 countries in different paces of development between 1983 and 2005, a study revealed that local environmental policies can sometimes be more influential than universal urban scaling laws, which may overlook local contexts. Specifically, countries with robust environmental regulations experienced a less negative impact of urbanization on emissions compared to those with weaker policies.

In China, where urbanization is accelerating, it is crucial for future policies to be tailored to the specific conditions and income levels of cities. This includes strengthening local environmental regulations, promoting green infrastructure, addressing income inequality, and encouraging community engagement. By focusing on these areas, Chinese cities can effectively reduce carbon emissions while navigating the challenges posed by urbanization.

4.6. Population Density

CO_2 emissions from the building and transport sectors have a power-law relationship with population density. For instance, in the United States, a 1% increase in population density reduces CO_2 emissions per capita by 0.79% [53]. Given this, in China, managing urban population density and promoting compact development are vital for achieving a low-carbon transition.

However, the impact of population density on emissions is not uniform across different contexts. For instance, while higher densities generally lead to reduced emissions in developed cities, this trend may not hold true in rapidly urbanizing areas, where increased density can lead to higher emissions due to factors like transportation needs and energy consumption patterns [53].

A consensus exists that higher population densities generally contribute to lower per capita CO_2 emissions, suggesting that compact urban designs may facilitate low-carbon development. Nonetheless, a notable gap in the literature is the lack of comprehensive analyses that consider both population and area simultaneously [53].

4.7. Public Awareness

Enhancing public understanding and acceptance of low-carbon living and implementing appropriate policy education is crucial. Public behavior and lifestyle play a crucial role in achieving a low-carbon life. In China, studies using CLA and input–output models indicate that household activities contribute to around 20% of total CO_2 emissions [14]. Significant cultural and economic differences exist between eastern and western China; thus, increasing low-carbon awareness should be tailored to local conditions. Regulatory and incentive measures should guide public low-carbon behavior.

To enhance public engagement with low-carbon initiatives, addressing the gap between awareness and action is crucial. Many individuals recognize the benefits of low-carbon living, but face barriers, such as economic constraints and lack of motivation. Actionable recommendations include targeted educational campaigns highlighting personal and community benefits, promoting community involvement through local sustainability projects, and developing incentive programs for adopting low-carbon behaviors. Additionally, leveraging social media to share success stories can inspire collective action. Recognizing cultural diversity across regions in China will ensure that these strategies resonate effectively, fostering a more engaged public in the transition to low-carbon cities [14].

Examining previous articles, we have gathered various factors that influence urban carbon emissions, with articles highlighting how compact urban models, efficient use of building materials, balanced economic growth, improved energy structures, effective policies, managed population density, and enhanced public awareness can contribute to reducing carbon emissions. These factors and their impacts on urban carbon emissions are comprehensively summarized and listed in Table 2.

Table 2. Literature review on influencing factors of urban carbon emissions.

Source	Year	Research Content
Guan, D.B.; Peters, G.P. et al. [41]	2009	China's carbon dioxide emission driving factors and energy-saving strategies
Long, W. D.; Bai, W. et al. [37]	2010	China's low-carbon city form and energy system model
Aumnad, P. [49]	2010	Analysis of Bangkok's energy utilization and planning methods
Ou, J.P.; Liu, X.P. et al. [38]	2013	Relationship between urban form and carbon emissions in Beijing, Shanghai, Tianjin, and Guangzhou
Diego, P.D.L.B.; Julian, D.M. [52]	2014	Impacts of urbanization and environmental policies on carbon emissions
Lin, B.Q.; Liu, H.X. [51]	2015	Analysis of carbon emission reduction and energy performance in construction, using counter-factual analysis methods
Su, X.; Zhang, X [40]	2016	Analysis of embodied energy and carbon emissions of three steel-construction residential buildings in China, based on LCA

Table 2. *Cont.*

Source	Year	Research Content
Du, Q.; Lu, X.R. et al. [44]	2018	Study of carbon emission factor decomposition and emission reduction strategies
Shen, L.Y.; Wu, Y. et al. [50]	2018	Decomposition and analysis of carbon emission influencing factors
Chen, X.; Shuai, C.Y. et al. [45]	2019	Analysis of carbon Kuznets curve and carbon emission driving forces
Lai, X.D.; Lu, C. et al. [48]	2019	Analysis of relationship between carbon emissions and energy consumption in construction industry, based on Kaya model
Ribeiro, H.V.; Rybski, D. et al. [53]	2019	Analysis of coupling effect of population density and carbon emissions
Li, D.Z.; Huang, G.Y. et al. [42]	2020	Analysis of driving factors and policy tools for carbon emissions in construction industry
He, J.H.; Yue, Q. et al. [39]	2020	Analysis of driving factors and policy tools of carbon emission in construction industry, based on LMDI model
Dong, K.Y.; Hochman, G.l et al. [43]	2020	Analysis of driving factors for global carbon dioxide emission growth, based on LMDI
Wu, Y.; Martens, P. et al. [14]	2022	Review of public perceptions and challenges of low-carbon urban transition in China
Sun H.P; Chen. T.T. et al. [46]	2024	Analysis of impact of digital finance on carbon productivity
Liang, X.; Liu, M. et al. [47]	2024	Research on relationship between economic growth, building technology innovation, and environmental sustainability

5. Methods for Calculating Urban Carbon Emission Indicators

5.1. Low-Carbon City Evaluation System

The systematic review study focusing on public awareness in lifestyle attitude and behavior shows that CO_2 emissions are influenced by multiple factors, allowing the analysis of national emission reduction policies through the extended Kaya identity decomposition of change rates. CO_2 emissions can be expressed as follows:

$$\mathrm{C} = \frac{\mathrm{C}}{\mathrm{CS}} \cdot \frac{\mathrm{CS}}{\mathrm{EP}} \cdot \frac{\mathrm{EP}}{\mathrm{EF}} \cdot \frac{\mathrm{EF}}{\mathrm{A}} \cdot \mathrm{A} = \mathrm{s} \cdot \mathrm{i} \cdot \mathrm{e_p} \cdot \mathrm{e_f} \cdot \mathrm{A}$$

where "C" stands for total carbon emissions, "CS" represents the carbon intensity of the energy source, "EP" denotes the total primary energy supply, "EF" refers to the final energy consumption, "A" signifies the overall activity level, "s" is the ratio of actual CO_2 emission to CO_2 emission without CCS, "i" is the carbon intensity, "e_p" is the inverse of energy conversion efficiency, and "e_f" is the aggregated energy intensity.

The change in CO_2 emissions can be expressed as follows:

$$\frac{\Delta C}{C} = \frac{\Delta s}{s} + \frac{\Delta i}{i} + \frac{\Delta e_p}{e_p} + \frac{\Delta e_f}{e_f} + \frac{\Delta A}{A} + residual$$

where the terms on the right side of the equation represent the effects of introducing changes ("Δ") in CCS ("s"), fuel mix ("i"), energy conversion efficiency ("e_p"), total energy intensity ("e_f"), and economic activity ("A") [54].

Based on the unit energy consumption method, a city carbon emission scenario analysis model can also be established using the following formula [55]:

$$\frac{\mathrm{M_0}}{\mathrm{GDP_0}} \times (1-\gamma)^{\mathrm{t}} = \frac{\mathrm{M_t}}{\mathrm{GDP_t}} = \frac{\mathrm{M_t}}{\mathrm{GDP_0} \times (1+\theta)^{\mathrm{t}}}$$

$$M_t = [(1-\gamma) \times (1+\theta)]^t M_0$$

where "M_0" and "GDP_0" mean the total carbon emissions and GDP of the city in the base year, respectively; "M_t" and "GDP_t", respectively, express the total carbon emissions and GDP of the city in year "t"; and "γ" and "θ" are the annual reduction rate of carbon emission intensity and the annual growth rate of GDP.

Guiding local governments in low-carbon development is challenging, due to traditional indicators not aligning with national carbon intensity reduction targets. Combining urban carbon intensity targets with a low-carbon city index system can provide a better evaluation method. For example, Xiamen's analysis identified energy intensity and energy mix as the main drivers of carbon intensity reduction, while Dalian's composite index peaked in 2014, indicating the effectiveness of low-carbon initiatives [56,57].

Some studies have developed urban carbon cycle models that consider carbon inputs, outputs, and temporary storage, measuring various forms of carbon to achieve carbon mass balance [58]. There are also comprehensive low-carbon city indicator frameworks that encompass economy, energy, society, transportation, waste, and water resources, using the entropy weight method for weight determination and evaluation [59,60].

There are differences between academia and governments in the use of low-carbon city indicators. Academics focus on energy use, while practical applications emphasize urban transportation. The researchers created a list of low-carbon city indicators across eight dimensions: economic, energy use, social, carbon and environment, urban transport, solid waste, water, and land use [61]. In addition, decision support systems enable integrated modeling of energy and carbon emissions, and multi-criteria decision analysis methods evaluate the sustainability of urban low-carbon development policies [62]. Academics emphasize per capita carbon emissions, while city managers focus on total carbon emissions. Improving statistical systems can bridge the gap, enhancing data collection and indicator predictability.

5.2. Life Cycle Assessment

A life cycle assessment (LCA) is required to determine the carbon emissions of a building over its entire life cycle, from raw material extraction to demolition and waste disposal. The operating phase of buildings is often the largest source of CO_2 emissions, including heating, cooling, lighting, and electrical use [63]. Several studies have explored methods for calculating greenhouse gas emissions from buildings, recommending alternatives like using different materials to further reduce carbon emissions throughout the building's life cycle [64,65]. In addition, combining a sustainable material selection decision framework with BIM tools can improve the usage of building materials throughout the life cycle, and simulate the influences of design, maintenance, operation, and use behavior modification decisions on building sustainability [66].

Although the construction phase contributes less to overall emissions, it remains essential for systematic low-carbon city construction. For the construction phase, a Chinese building construction model can be developed to study the relationship between building stock, material stock, and carbon emissions [67]. According to the evaluation results of the model, the government should set reasonable limits on existing stock, control new construction scales, minimize demolition, ensure that buildings meet their designed service life, and extend their lifespan through renovations.

5.3. Spatiotemporal Simulation of Carbon Emissions

In view of China's vast territory and uneven population density, the spatiotemporal simulation of carbon emissions is essential for understanding low-carbon city development on a macro level and facilitating macro-control.

By integrating spatiotemporal correlation theory with night-light datasets, such as those from the Defense Meteorological Satellite Program/Operational Linescan System (DMSP/OLS) and the Suomi National Polar-orbiting Partnership/Visible Infrared Imaging Radiometer Suite (NPP/VIIRS), a robust methodology has emerged for estimating the dynamic evolution of urban carbon emissions. This approach commonly employs regression models or statistical frameworks to correlate night-light intensity with carbon emissions in urban areas. For example, utilizing night-light imagery to estimate the carbon emissions of 334 prefecture-level cities in China over multiple time periods has provided accurate, long-term data, supporting sustainable urban development and carbon reduction strategies. The data also clearly reveal the spatial autocorrelation of urban emissions, demonstrating that emissions are not uniformly distributed, but follow localized patterns driven by development and energy consumption [68,69].

Furthermore, the dynamic interactions between urban land use efficiency, industrial transformation, and carbon emissions illustrate significant spatial heterogeneity. Regions with higher land use efficiency and ongoing industrial restructuring tend to exhibit lower carbon emissions, highlighting the importance of spatial factors in shaping emission patterns [70].

Multiple methods for calculating urban carbon emissions have been analyzed, covering the low-carbon city evaluation system, life cycle assessment (LCA), and spatiotemporal simulation of carbon emissions. These explore the use of extended Kaya identity decomposition, urban carbon cycle models, and the integration of low-carbon city indicators to guide local governments in low-carbon development. LCA identifies the operational phase of buildings as the largest source of CO_2 emissions, offering recommendations for emission reduction. Furthermore, dynamic simulations of carbon emissions across time and space have been analyzed to support sustainable urban development. Table 3 shows the summary of the literature review related to urban carbon emission accounting methods.

Table 3. Literature review on urban carbon emission accounting methods.

Source	Year	Research Content
Reina K.; Yuzuru M. et al. [54]	2006	Climate stabilization program
Gustavsson, L.; Joelsson, A. et al. [63]	2010	Life cycle energy and carbon emissions of timber-framed apartment buildings
La Roche, P. [64]	2010	Calculation and reduction strategies of greenhouse gas emissions from buildings
Bank, L.C.; Thompson, B.P. et al. [66]	2011	Integration of sustainable building materials and BIM
Kellett, R.; Christen, A. et al. [58]	2013	Urban carbon cycle simulation and quantification
Lin, J.Y.; Jacoby, J. et al. [56]	2014	City carbon intensity target is combined with low-carbon city index for assessment
Biswas, W. K. [65]	2014	Analysis of greenhouse gas emissions and energy consumption in whole life cycle of university engineering buildings
Duan, Y.; Mu, H.L. et al. [57]	2016	Evaluation and trends of low-carbon economy in Dalian
Tan, S.T.; Yang, J. et al. [59]	2017	Low-carbon city evaluation index and global urban development evaluation
Azizalrahman, H.; Hasyimi, V. [60]	2018	Urban low-carbon performance evaluation model

Table 3. *Cont.*

Source	Year	Research Content
Lou, Y.L.; Jayantha, W.M et al. [61]	2019	Compilation and applicability of low-carbon city indicator list
Bi X, Wang D [55]	2020	Effects of industrial structure and energy consumption on urban carbon emissions
Dong, Y.; Jin, G. et al. [69]	2020	Spatial and temporal characteristics of urban land use and carbon emission in Yangtze River Economic Belt
Wang, Y.N.; Fang, X.L. et al. [62]	2021	Urban low-carbon development quality evaluation and regional difference analysis
Chen, J.D.; Gao, M. et al. [68]	2021	Estimation of carbon emissions in prefecture-level cities in China and analysis of regional differences
Zhang, Y.; Hu, S. et al. [67]	2022	Carbon emission path analysis and model establishment in China's construction industry
Lu, X.H.; Zhang, Y.W. et al. [70]	2022	Carbon emission estimation and land use efficiency analysis of urban agglomerations

6. Urban Carbon Reduction Methods

6.1. Low-Carbon City Model and Policy Recommendations

Urban carbon emissions in China predominantly arise from fossil fuel consumption in buildings, industry, and social activities. To effectively reduce urban carbon emissions, establishing scientific low-carbon city models is essential for accurately quantifying these emissions.

Various studies have developed low-carbon city models, categorizing them into urban transport, building emissions, and production emissions, or using the DPSIR framework for assessments [71]. The common model framework is based on the following formula: CO_2 emissions = KE, where E represents various energy consumption, and K is the carbon emission intensity factor. The formula is as follows [72]:

$$CO_2\ Emission = P \times \frac{GDP}{P} \times \frac{E}{GDP} \times \frac{CO_2}{E} - i$$

These models help in understanding and planning for the reduction of urban carbon emissions through various strategies. To evaluate urban carbon emissions, economic factors, such as population ("P"), per capita GDP ("GDP"), energy intensity ("E"), and changes in technological innovation, structural optimization, and policy implementation, are also taken into account [73].

An Integrated Model of Economy and Climate (IMEC) has also been developed, based on the basic linear equation of the input–output model by Wassily Leontief; this equation is as follows:

$$(I - A)X_t = Y_t$$

$$(I - A_c)X_t = V_t$$

This model provides a foundation for analyzing urban energy consumption patterns and their relationship with economic and environmental factors. Building on this concept, the urban energy consumption model identifies three main processes: input, transformation, and output. To achieve low-carbon development goals, cities can adopt the following strategies to reduce carbon emissions:

- Input Stage: Prioritize renewable energy usage over high-carbon energy sources such as fossil fuels.
- Transformation Stage: Improve the efficiency of fossil fuel use in industrial production, buildings, and transportation.

- Output Stage: Increase carbon sinks, such as expanding vegetation areas and protecting wetlands, to absorb CO_2 emissions within the city.

  Specific measures for carbon reduction in each aspect of urban development include:

- Green Buildings and Low-Carbon Living

Building design should be integrated with the natural environment to reduce energy consumption, including utilizing energy-efficient materials and technologies, promoting energy-efficient appliances, and raising public awareness of energy conservation.

- Compact Urban Spatial Layout

Optimize regional layouts and infrastructure configurations, and promote medium- to high-density aggregation and resource-sharing strategies to improve resource utilization efficiency.

- Enhancing Energy Utilization Efficiency

Adjust the industrial structure, develop low-carbon, technology-intensive industries, eliminate backward industries, and promote the development of renewable energy [73].

To reach peak carbon emissions in 2026, China needs to reduce its average annual GDP growth to less than 4.5% by 2030, and reduce its energy intensity by 43% and carbon intensity by 45% between 2015 and 2030.

6.2. Low-Carbon Building Design and Life Cycle Evaluation

In the various stages of the building life cycle, the use stage accounts for the highest proportion of greenhouse gas emissions (68.92%), followed by the production stage of building materials (23.87%). Retrofitting contributes 6.43% of emissions, while emissions from other phases (such as waste disposal, construction, demolition, and material transport) are relatively negligible [74]. To reduce environmental impact, implementing life cycle assessment (LCA) during the early design stages is essential. Key considerations include focusing on low-carbon designs, optimizing building orientation, and utilizing bio-based materials such as engineered wood [75,76].

In practical applications, such as the LCA evaluation of public buildings in Shenzhen, it has been shown that these efforts slow the growth of CO_2 emissions without reversing the trend [77]. To address this issue, governments should adopt a comprehensive approach to reduce carbon emissions while maintaining economic stability. Specific strategies include the following [73]:

- Industrial Structure Adjustment: Develop low-carbon industries and reduce reliance on heavy industry and manufacturing, which are major emissions sources.
- Energy Consumption Control: Implement strict controls on total energy consumption, with a particular focus on reducing coal consumption, which remains a significant contributor to urban carbon emissions.
- Technological Innovation: Promote technological advancements that improve energy efficiency, such as the adoption of BIM-supported LCA models for detailed assessments of a building's lifecycle environmental performance, to inform emission reduction strategies.

These strategies, alongside policies reducing carbon emissions from building materials, can enhance urban low-carbon transitions and promote energy-saving technologies for sustainable development.

The paper presents a thorough analysis of urban carbon emission calculation methodologies, highlighting the significance of developing scientific low-carbon city models to quantify and cut emissions. An array of frameworks and models that aid in the comprehension and planning of emission reduction methods have been investigated. This essay also examines LCA in the context of building design, emphasizing the critical role that early-stage LCA plays in minimizing environmental effects, as well as the considerable influence that the operating phase has on greenhouse gas emissions. Table 4 provides a comprehensive literature review of these techniques and a summary of the conclusions of past articles.

Table 4. Literature review on urban carbon Reduction Methods.

Source	Year	Research Content
Chen, F.; Zhu D.J. [72]	2013	Analysis of Shanghai's strategy for developing a low-carbon city
Basbagill, J.; Flager, F. et al. [75]	2013	Early building energy-saving design
Mi, Z.F.; Wei, Y.M. et al. [73]	2016	Integrated economic and climate model
Yang, X.N.; Hu, M.M. et al. [74]	2018	Low-carbon design of buildings
Huang, Y.Y.; Duan, H.B. et al. [77]	2019	Quantitative analysis of carbon dioxide emissions from public buildings in Shenzhen
Churkina, G.; Organschi, A. et al. [76]	2020	Carbon storage potential of engineered wood in mid-rise urban buildings
Hu, F.; Tang T.L.P. et al. [71]	2024	Low-carbon evaluation of tourist attractions

7. Discussion and Future Directions

The development of low-carbon cities in China presents several challenges, including policy implementation discrepancies, micro-level variations, and public engagement issues. Despite progress in policy and technology, regional disparities necessitate adaptable frameworks that consider local economic and cultural differences. Additionally, micro-level differences in urban forms and sectoral contributions also require targeted interventions. Public resistance and insufficient awareness further complicate the adoption of low-carbon strategies.

To address these shortcomings across the literature, our study finally suggests several actions, in accordance with these shortages, by which China can improve its low-carbon city strategies and contribute significantly to global climate goals. Further detailed implementation suggestions can be referred to in Table 5, which highlights the critical issues in low-carbon city development and provides targeted solutions.

Table 5. Key challenges and solutions in low-carbon city development.

Category	Key Challenges	Specific Problems	Proposed Solutions
Policy and implementation	Policy–practice gap	- Lack of effective implementation mechanisms - Inconsistent application of policies across regions	- Develop flexible, region-specific policy frameworks - Improve coordination between national and local authorities - Implement robust monitoring and evaluation systems
Sectoral emission reduction	High emissions in key sectors	- Inefficient energy use in residential and commercial buildings - High carbon footprint from transportation and industrial activities	- Establish stricter energy efficiency standards - Promote sustainable urban planning and public transportation - Encourage adoption of renewable energy sources

Table 5. *Cont.*

Category	Key Challenges	Specific Problems	Proposed Solutions
Technological and financial barriers	Limited adoption of low-carbon technologies	- High costs and limited access to financing - Gaps in technical knowledge and capacity among stakeholders	- Provide financial incentives and subsidies for green technologies - Develop public–private partnerships - Conduct training and capacity-building initiatives
Public engagement and behavior change	Low public awareness and participation	- Insufficient public understanding of low-carbon benefits - Disconnect between knowledge and action - Limited community involvement in sustainability initiatives	- Promote low-carbon living through campaigns, school curricula, and digital media- Encourage local projects and reward sustainable behaviors - Leverage social media and community leaders to share success stories and enhance credibility for low-carbon initiatives - Establish feedback channels to address community needs and tailor strategies to align with local traditions and values

(1) Lack of effective evaluation of emission reduction measures: Current studies on the effectiveness of emission reduction measures in low-carbon cities remain insufficient. Future research should prioritize collecting practical data and applying evaluation methods to verify the effectiveness of implemented measures. Additionally, further integration and evaluation of strategies, policy technologies, and public participation in low-carbon cities are encouraged. This will facilitate the development of consolidated methods that can serve as valuable references for future scholars and practitioners, ensuring the effectiveness and practical applicability of these approaches.

(2) Application of policy technologies: Regarding the policies, by understanding the overall shortcomings in the development of low-carbon cities, this study emphasizes the need to enhance collaboration between academia and practitioners, fostering the development of efficient policy tools and implementation strategies. Programs like the practitioner–scholar program or research–practice collaboration platforms should be promoted to bridge the gap between academia and practice in urban design and architecture.

(3) Public participation: Public lifestyle choices have a significant impact on carbon emissions, yet current efforts to promote low-carbon awareness among citizens are inadequate. It is recommended to enhance public awareness through targeted approaches.

- Proactive awareness should primarily focus on regional issues: In rural or non-remote areas, raising awareness of deforestation and sustainable agricultural practices is important. In urban areas, where waste generation is often higher, raising public awareness of reducing packaging waste and optimizing transportation utilization should be prioritized.
- Passive guidance strategies: Implementing measures like comprehensive recycling systems and optimizing urban transportation planning can subtly educate citizens. Efficient transportation route planning not only reduces carbon emissions, but also encourages public cooperation, fostering mutually beneficial outcomes for cities and their inhabitants.

8. Conclusions

This article addresses a critical gap in current research by moving beyond regional studies to offer a macro-level synthesis of low-carbon city development in China. While existing research often focuses on isolated regional perspectives, this review highlights how these efforts must be aligned with broader national goals. It identifies regions that need tailored low-carbon strategies based on their specific resources and conditions, ensuring more effective and contextually relevant solutions.

The development of low-carbon cities is key to mitigating climate change and promoting sustainable urban growth. This review synthesizes the current research landscape, noting significant advancements and persistent challenges, such as limited integration of micro- and macro-level research, a disconnect between policy and practical application, and insufficient focus on public participation.

To address these issues, future research should prioritize integrated frameworks that connect local insights with national strategies, enhance community engagement, evaluate the real-world effectiveness of policies, and explore technological innovations that improve urban energy efficiency and resource management. By focusing on these areas, future studies can provide more cohesive and effective approaches for advancing low-carbon city development.

In conclusion, while progress has been made, a holistic approach is essential to overcome existing challenges and achieve the dual goals of sustainable urban development and climate change mitigation. This review sets the foundation for future research, guiding efforts towards a deeper understanding of low-carbon city initiatives and their successful implementation.

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