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Review

Sustainability of Low Carbon City Initiatives in China: A Comprehensive Literature Review

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Abstract: Low carbon city (LCC) has emerged as the latest sustainable urbanism strategy in China as a response to climate change impacts. Yet, minimal scholarships have explored the sustainability of the urban planning model towards understanding the complexity of the components. Using a two-step triangulation approach, this paper presents a structured overview of the LCC initiative in China as it relates to the transition to a sustainability paradigm. The data collection approach includes a comprehensive review of 238 articles on LCC to identify and categorize LCC components. Furthermore, discourse and framing analysis was used to develop and synthesize a conceptual framework for assimilating the components into four core sustainable development principles: Integration, implementation, equity, and scalability and replicability. The results indicate that LCC development in China is bias towards economic and environmental technological innovations and strategies. Additionally, several critical sustainability issues of LCC pilots were identified. These include a lack of social equity planning concerns for the most vulnerable population, dearth of social reforms that cater to lifestyle and behavioral change, top-down planning and decision-making processes, a technocratic rationalization planning approach, inconsistent LCC targets on inter-generational justice concerns, absence of an effective national "sharing and learning" city–city network system, and several barriers to implementation. We conclude that the applied theoretical and conceptual inquiry into the field of LCC is pertinent to mitigate climate change and achieve sustainable urban development.

Keywords: sustainable development; Chinese literature; low carbon city; climate change; mitigation; urban planning; systematic review; equity; sustainable energy; China

1. Introduction

In recent times, China stands at the forefront of the international polemics on climate change. This is because the country has experienced rapid functional and structural economic development, growing ascendancy in competitiveness in global trade, unparalleled population growth and urbanization rate, and physical and socio-spatial modernization. Driven by high investments in the manufacturing industry [1–3], the economy over the last three decades has experienced approximately 10% annual GDP growth, resulting in increased per capita income and improved standards of living [4,5]. In another breath, urban development in China is characterized as rapid and unbalanced [6]. Between 1978 and 2010, the total number of cities snowballed from 198 to 657, with eight megacities having more than 10 million people and 103 cities having over one million people [7]. At the end of 2014, the urbanization rate of China had increased to 54.77%, with continued projected growth to 65% by 2030 and 75% by 2050 [8–10]. These driving forces have caused a massive upsurge in demand for energy [11], as today, urban areas represent 84% of the primary energy consumption in the country [12]. This is based on a coal-dominant energy system [13], which accounts for approximately 70% of total energy consumption [14–17]. This increasing energy consumption and coal dependency of the urban energy system has increased greenhouse gas (GHG) emissions, as China has become the world's largest energy consumer and carbon emitter [18,19]. A recent report by the National Bureau of Statistics [20] suggests that despite a decline in GHG emissions between 2013 and 2016, emissions grew by 2.3% in 2018 due to a surge in urban construction. Therefore, after three decades of rapid physical and socio-spatial modernization, the country is facing significant negative externalities [16]. Local environmental pollution [6,16,21–23], ecological deterioration [24], and energy shortage [21,25] have created health risks [26], have affected people's quality of life [27], and resulted in substantial economic losses [28] in megacities such as Tianjin and Beijing [29]. Concomitantly, China's cities are vulnerable to climate change impacts [17,30], as some cities have inadequate seawall defenses in low-lying areas [5], and are therefore exposed to flooding and extreme rainstorms [23]. In addition to this, some experience droughts from reduced precipitation, which can be attributed to low urban institutional capacity that creates limitations in climate governance and planning [31]. These complex and intractable problems have heralded a call for action, to balance economic growth, society, and environmental protection in the face of global climate change.

Towards this end, the polysemic concept of LCC was promulgated as a strategic response to climate change and urban sustainability [32]. This strategy has the potential to disrupt traditional thinking and enable cities to explore and scale-up GHG mitigation activities, transitioning from business-as-usual to avoid long-term carbon lock-in [15,33,34]. Proven by its international commitments and local actions, the country has established specific targets for GHG emissions and in the meantime, expands the LCC ideology. This includes short-term targets (40% by 2020 from 2000 levels) established during the Copenhagen Conference in 2009 [35] and long-term binding goals (60–65% by 2030 from 2005 levels, and peak it by 2030) established through its ratification of the 2015 Paris Agreement [36]. Besides, in 2010, the National Development and Reform Commission (NDRC) established the first LCC pilot cities and provinces program based on the premise of "experimentation under hierarchy" or centrally coordinated policy experimentations [8,37]. The lessons learned served as guides for subsequent pilot projects launched in 2012 (batch 2) and 2014 (batch 3; see Figure 1), [35,38] and allowed local governments to apply low carbon interventions into their planning and management models. Furthermore, the government has explored scientific approaches that undergird development in a sustainability realm [33], and national policies that advance China's utopian vision of an LCC [39,40]. These approaches and policies are disseminated in the 18th Chinese Congress declaration and report of ecological civilization (2012) [1,23,41], the 12th (2011–2015) and 13th (2016–2020) Five Years Plans (FYPs) [42], and the National New-type Urbanization Plan (2014–2020) [6]. Furthermore, they provide the impetus to shift the development path of cities and exemplify China's commitment to implementing green regenerative development approaches within urban planning projects.

Since LCC will continue to be prominent in China, it is imperative to ensure that the current strategy embraces and integrates the fundamental principles of sustainability. Extant Chinese scholars have focused on the sustainability of LCC planning [7,36,43–45]. Among these studies, Yang et al. [43] used a content analysis to conduct a comparative analysis of 12 plan documents (eco-city—four plans, LCC—four plans, and new towns—four plans) on sustainable urban strategies and assessed the integration principle of sustainability (planning, economy and industry, and landscape and transportation). The study indicates that although the foci of LCC are to reduce GHG gases in cities, the primary interventions utilize a disruptive technologically innovative approach towards higher resource productivity for pollution reduction. Guo et al. [36] employed a carbon-neutral coefficient (CNC) to understand regional sustainability by examining the forces that secure long-term spatiotemporal differences in local carbon balance. Tang et al. [45] explored essential low carbon conceptual countermeasures for sustainable development of the tourism industry. Besides promoting ecological consideration, the study recommended the need for education and awareness raising, standardization and institutionalization, demonstration, and popularization of green standards that will ensure more social, economic, and environmental co-benefits. Li-qun et al. [44] hypothesized that the primary goal of the LCC is to engender a green and sustainable city. However, to fully achieve a sustainable development, it requires full integration of low carbon lifestyle in planning and urban design among ordinary people. Through a critical review of sustainable urban development models in China, Liu et al. [7] found that while LCC supports carbon efficient economy, energy efficiency, and economic growth, it is devoid of social and environmental protection aspects of sustainable development.

Figure 1. Geographical location of China low carbon pilot cities and provinces.

The above studies effectively emphasize the integration components of sustainability, but Liu et al. [35] intimated a need for an integrative analytical framework to gauge urban sustainability within a decentralized urbanization process. As observed in the literature above, there are significant gaps in assessing LCC through a sustainable development lens. This is a critical research realm, as sustainability is considered the utopian vision of LCC in China [46]. This approach needs to change parochial boundaries, rather than wholly emphasizing economic growth and technological innovation as the core of LCD. Therefore, this research utilized the core endogenous principles of sustainable development by presenting a balanced approach to advance the current literature and practice of LCC. By doing so, the paper elaborates on discussions and analysis to improve the research and theorization on the relationship between climate change mitigation and urban sustainability. The study seeks to address objectives focusing on (1) identifying the principal components and policy responses of LCC in China; (2) analyzing the extent at which these components have integrated the core principles of sustainable development; and (3) identifying the gaps and future research opportunities for LCC development. The remaining sections of this paper are organized as follows. Section 2 describes the materials and methods used for the review of the selected literature, including the theoretical background and analytical framework. Section 3 presents the results and discusses the relevant principles of sustainable development for an LCC. Section 4 presents concluding remarks with recommendations for future research.

2. Materials and Methods

2.1. Overview and Research Philosophy

To obtain an in-depth insight into the taxonomy of the LCC concept and derive a comprehensive response to research objectives identified in Section 1, a conceptual analysis was conducted following procedures described in Jabareen [47], which is based on the grounded theory. Our process was divided into two steps (Figure 2). Step 1 was the identification and categorization of the state-of-the-art literature of LCC in China. In step 2, a conceptual framework was developed and synthesized for assimilating the components of LCC in the core sustainable development principles. As a result, the study was grounded in qualitative methodological strategies for data collection and analysis that is ideal when a topic of investigation is new [48]. Therefore, we utilized a triangulation approach, which uses two or more methods to study a phenomenon, such as the LCC concept [49]. Methodological triangulation is a preferred and powerful technique that is valuable in "confirming findings and ensure that they are robust and well-developed, more comprehensive data, increased validity and enhanced understanding of the studied phenomena" [49]. The main point was to gain an understanding from different perspectives of investigated phenomena. In our study, the main triangulation methods used were a systematic literature review, discourse and framing analysis, semi-structured interviews, and scientific validation.

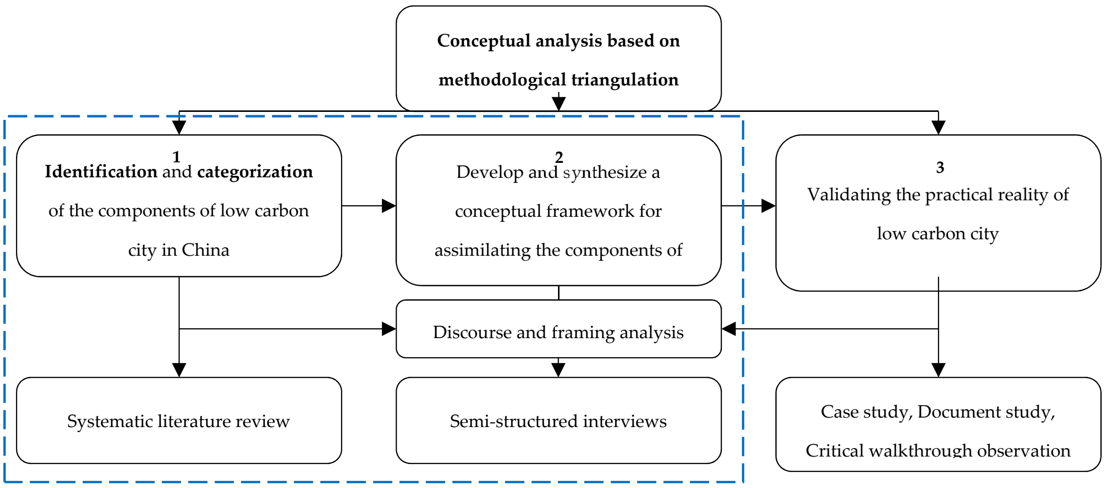

Figure 2. The research methodological approach for developing a conceptual framework for sustainability assessment of the low carbon city (LCC) initiative in China. The area delineated by the dashed-line rectangle (step 1 and 2) illustrates the specific approach covered in this paper.

2.2. Identification and Categorization of the Literature on LCC in China

Systematic Literature Review

Provided that the LCC model is profoundly interdisciplinary, the systematic literature review provides an indispensable basis for collecting and analyzing data to identify and categorize literature on LCC. This is based on using a pre-specified and standardized technique. Our approach was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA), available at http://prisma-statement.org/, and incorporates two distinct tasks: Data collection (search strategy, and document screening) and, data extraction and categorization. To explore the literature and gather relevant resources, a broad search protocol was utilized to identify a maximum number of articles on LCC. To do this, several leading multi-disciplinary academic publishing and distribution bibliographic databases were consulted: Google Scholars, Web of Science, Scopus, MDPI, ScienceDirect, Springer, SAGE Publications, Taylor and Francis, and IEEE Xplore (Figure 3c). After selecting the sources of literature, the next step involved defining the keywords to search these databases for the relevant publications. Several synonyms and related concepts were used as search strings in the journal databases: "low carbon pilot", "low carbon cit", "low carbon eco-cit", "low carbon ecological cit", "low carbon energy system", "low carbon planning", "low carbon development", "low carbon city implementation", "low carbon economy", "low carbon lifestyle", "low carbon societ", "low carbon communit", "low carbon neighbourhood", "low carbon district", and "China", "Chinese cities", "Chinese Provinces", and "Chinese pilot cit". The search was limited between 2008 and 2017, given that the first pilot initiative was launched in 2008 in the cities of Shanghai and Baoding as a joined initiative with the Worldwide Fund (WWF) for Nature [50]. The initial searches, which were carried out in August 2017, yielded 2136 articles in total, including duplicates. The articles were filtered by removing the duplicates by carefully reviewing the titles of the articles, reading the abstracts, and reviewing the article keywords. Following this, 294 relevant articles (minus the articles from August 2017 to 2018 and policy literature as well) that encapsulate the LCC in China and are of good quality were selected. The quality of an article is characterized by the suitable scope, thoroughness and consistency, precision and conciseness, and effective evaluation and synthesis [51]. The 194 eligible papers went under the in-depth study of qualitative synthesis of empirical research to identify the components of LCC. It is important to note that the abstracts of numerous articles from the China Knowledge Resource Integrated (CNKI) database were initially reviewed; however, only English language journals were used in this study. A supplemental search was conducted in April 2018 using the Google Scholars and Elsevier Scopus to identify literature that was published after the initial search, and 41 articles were identified. Additionally, the study utilized snowballing to identify relevant studies cited in the bibliography of reviewed literature (three studies). Overall, a total of 238 studies were identified, authored from 2008 to 2018, covering 18 thematic areas and a total of 62 journals (Figure 3).

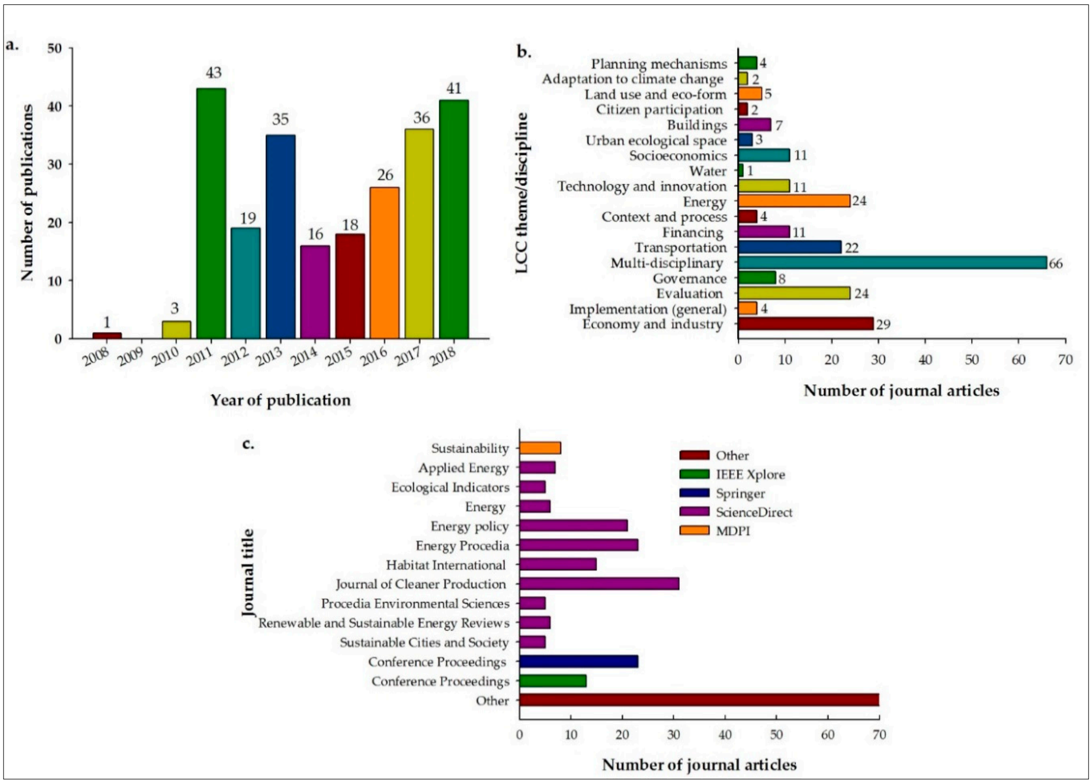

Figure 3. Growth in publications on LCC in the scientific literature (with 3 or more publications) based on publishing and distribution bibliographic databases, where "Others" imply journals with two or less publication.

Data extraction of the literature generated was conducted using the qualitative analysis to identify thematic categories with coherence, and group the main components of LCC through data deduction.

The qualitative analysis includes extensive reading and rereading, deconstructing the literature, identifying and naming concepts, along with categorization and synthesizing the components into a logical framework [47]. The first phase of the extraction of concepts included the identification of the main components as macro themes of importance. To identify the main LCC components, we used knowledge from practice, conducted semi-structured interviews with low carbon city researchers and reviewed the grey literature that spans several government policy reports and international technical publications and documents (for example, Baeumler et al. [33]). The second phase of the coding of the literature included the identification of various sub-components as micro themes of importance. An excel database was created with the component and sub-component identified from the literature, with a continuous comparison of similarities and differences from literature and practice. Part of this approach encompasses rounds of coding followed by a discussion to rationalize categorization.

2.3. Assimilating the Components of LCC in the Core Sustainable Development Principles

Discourse and framing analysis (DFA) was used to contextualize how Chinese cities were promoting the LCC concept towards achieving urban sustainability. DFA is long recognized as an imperative tool that can be used to demystify sustainability [52].

The term sustainable development came into widespread policy use with the publication of the Brundtland Report, “Our Common Future” by the World Commission on Environment and Development (WCED) in 1987. While there are myriads of definitions and conceptualizations of the concept since the publication of the official report, the most cited definition is a “development that meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations” [53]. Despite the widespread usage of the definition as a theoretical framework for urban development, implementation is hardly facile. The notion of sustainability emanated from the need to balance social and environmental systems that prevailed as a result of economic development, which was unaware of environmental degradation and growing social inequalities. The increasing development intensity and ecological footprint endangers and disrupts the capacity of critical urban and regional systems to function. More recently, the 2030 sustainable development goals (SDGs), beginning in 2015, and includes 17 goals and 169 targets, seek to make efforts to end all forms of poverty (goal 1), reduce inequalities (goal 10), tackle climate change (goal 13), and ensure access to affordable and clean energy (goal 7), while ensuring a balanced approach to creating sustainable cities and communities (goal 11) [54].

A previous study by Hunter et al. [55] identified four sustainable development principles: (1) Integration; (2) implementing; (3) equity (intra-generational, procedural, and inter-generational); and (4) scalability and replicability (Figure 4). Based on Figure 5, the LCC components identified were categorized and integrated into the four core endogenous sustainable development principles [55]. The integration principle posits that the quest for sustainability should balance environmental, societal, economic, and governance considerations, and their interdependencies that are intrinsic for improving citizens’ quality of life among other co-benefits. The implementing principles focus on the conversion of strategies and plans into actions. The principle of equity is a quintessential concept of sustainable development, and calls for fairness, inter and intra-temporal accessibility to resource utilization, and democracy in the decision-making processes. As a result, the three underlying sub-dimensions of equity (intra-generational, procedural, and inter-generational) should be intertwined into the LCC phenomena to maximize the multiple benefits to society. Intra-generational equity focuses on fairness and distributional co-benefits within the same generation, with prioritization of those in the greatest need (for example, low-income groups, vulnerable, elderly, and disabled). Inter-generational equity emphasizes inter-temporal parity and fairness between generations pertaining to consumption, conservation, and utilization of resources, the satisfaction of individual well-being and human needs, protection of environmental quality, and economic diversity and vitality [56]. Procedural equity focuses on the inclusion of stakeholders at different levels in the planning and development decision-making process [57] through engagement approaches such as participation, partnership, and collaboration [7,8,55,58]. Finally, scalability and replicability entail the transferability of the LLC pilot and demonstration projects to the whole city level or international duplication of the project's strategies and technologies in other geographical areas, respectively. It helps to build technology and knowledge transfer to communities and cities that have limited skills, as well as provide unique business models, good practices, and lessons learned to enhance the continuity of excellent sustainability practices and ensure maximum impact. Practically, both the intrinsic growth and replication of LCC innovations increase the spatial scale and coverage of LCC and, thus, have a more significant impact in terms of low carbon urban development.

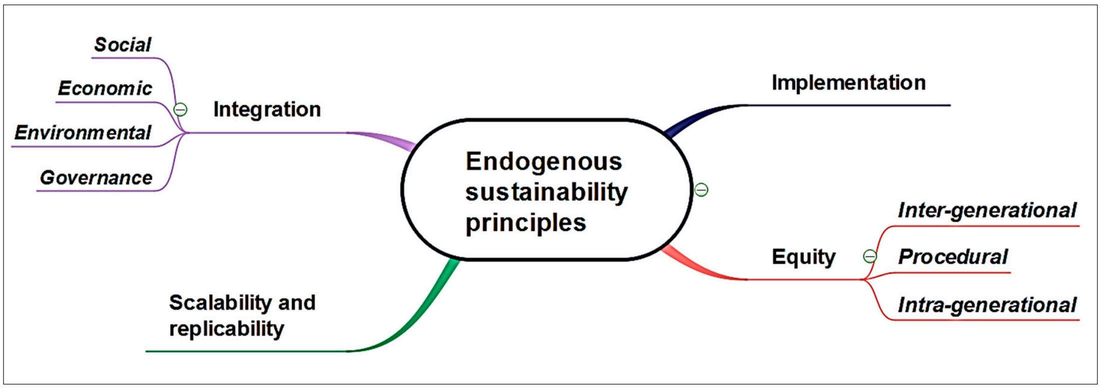

Figure 4. Theoretical framework showing the four endogenous principles of sustainable development [55].

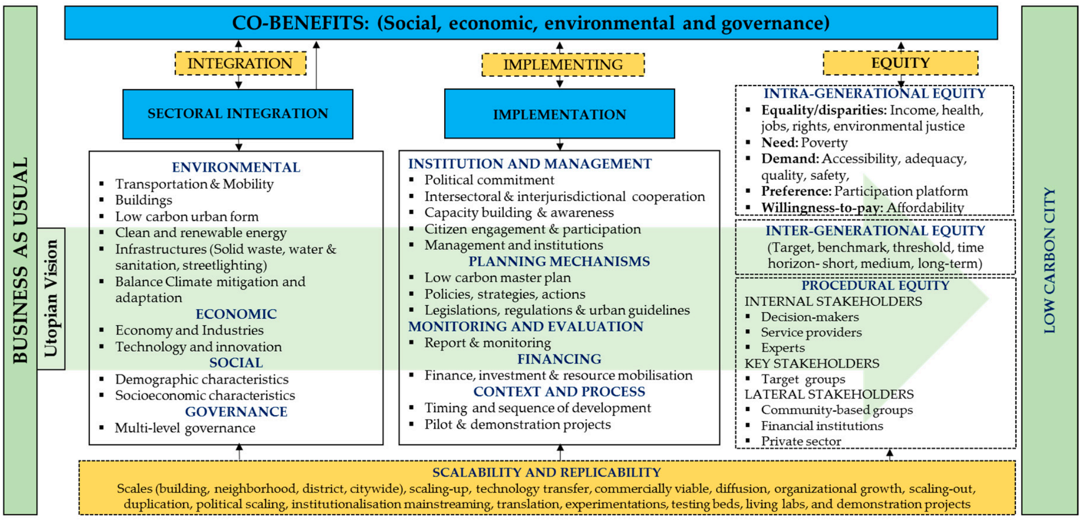

Figure 5. Conceptual framework integrating LCC into the sustainable development principle.

Validation of the analytical framework was undertaken on two levels to determine if the concepts were easy to understand and if the framework presented a reasonable analytical approach for studying the phenomenon from different disciplines [47]. Firstly, semi-structured interviews with six professional planners (two professors and two researchers from Tongji University, one researcher from Shanghai Tongji Design Institute, and one from Fudan University) from leading urban planning universities in China were conducted. Secondly, the conceptual and analytical frameworks were presented at the Association of European Schools of Planning (AESOP) Congress in Gothenburg, Sweden, from 10–14 July 2018. This presentation sought to discuss and receive feedback from a broad international audience on the frameworks, as well as gauge current research discourse in sustainable development, climate change, and emerging scientific and technological trends in LCC development.

3. Results and Discussion

3.1. Integration

The social system encompasses the culture, the cost of living and education in an area, which promotes low carbon living and values through changes in consumer attitude, behavior, and lifestyle to build a mainstream perspective [59]. The social dimension of LCC places people at the centre of a successful transition to a low carbon society. This is because they are the main drivers of climate change and the essential agents that can profoundly redirect development trajectories. They can also reduce the demand for final urban services [60]. The impetus for macro and microeconomic growth, technological fixes, their interconnectivity with environmental issues, suggests the social dimension is usually overlooked and under-implemented in Chinese literature and practice on LCC [33,61,62]. This narrow focus suggests that there is an immense likelihood that efforts to connect LCC, sustainable development, and improvement in the quality of life will stymie if social dimensions are not addressed more broadly in low carbon plans [26,63].

Quite recently, however, several studies on LCCs have explored a wide range of socio-economic and socio-demographic characteristics as the primary driving force that accelerates or thwarts GHG reduction targets at the local level. Some studies have established a direct correlation between urban residents behavior, low carbon economic development, and building low carbon communities [26,42,64]. The four strands of literature within this context have explored the central factors, as presented in Table 1. Firstly, driving forces such as population growth, affluence, urbanization level, knowledge and awareness, and technology have actualized changes in the urban lifestyle since the 1970s and have contributed significantly to carbon emissions [65,66]. Secondly, the occupant or household behavior is a significant determinant of household carbon emissions from energy use [67–69]. Moreover, consumer willingness to pay for low carbon (LC) products has become a topical issue to both policymakers and enterprises, due to the environmental implication throughout the lifecycle of a product [70,71]. Transportation or commuter modal choices are also influenced by socio-psychological or attitudinal factors, and low carbon factors [4,60,72]. As an illustration, Geng et al. [73] evaluated the behavioral response of urban residents in Shanghai, Beijing, Guangzhou, Jinan, and Hangzhou to 22 (central) government low carbon transport policy options. They found administrative policies such as driving restrictions, accessible and reliable public transport (public transport density, frequency, route, and infrastructure), and multi-level road planning are indispensable tools for reducing the need to optimize the use of public transportation options.

After the preceding three decades of double-digit economic growth, propelled by industrialization and modernization, China's economy has transitioned to 'the new normal', a period of rebalancing and structural adjustment [74–76]. This represents a conspicuous shifting and reorientation [77] in an emphasis from high-growth investment-led production and consumption [1,78] to value-added service industries [21] that can stimulate urban productivity, optimization of the urban industrial structure, and promote sustainable growth [2,79,80]. This structural rebalancing also involves reducing the pollutions associated with economic growth and lowering energy and material intensity, to expedite the shift to a low carbon economy (LCE) [77]. From an LCE perspective, China's nascent manufacturing industry is the dominant driving force for energy consumption, and a significant source of pollution, carbon emissions (70%), and waste generation, which impose high costs on the economy, urban public health, and the environment [1,19]. In fact, Cai et al. [30] found that economic scale and structure is the main among ten driving forces of GHG emissions in 286 prefecture cities, where a current economic trajectory of 7% GDP growth can lead to 6% growth of CO_2 emissions. Such findings support the dominance of economic strategies in LCC pilots [8,81]. To guide the LCE, central and local administrations have developed a series of strategic plans with an emphasis on upgradation and innovation, to ensure a more balanced, higher-quality growth transition. These include 11th–13th (FYPs), the Made in China 2025 plan (2015), the National Medium- and Long-term Program for Science and Technology Development (2006–2020), and the Industrial Green Development Plan (2016–2020) [82].

Table 1. Integration principle: Social dimensions of the China LCC initiative.

Sub-Dimensions	Components	Sub-Components in the Literature	References
Social	Socio-economic and socio-demographic characteristics	1. Urban lifestyle • Demographic characteristics: Population growth, population size and density, urbanization level, knowledge, and awareness. • Socio-economic characteristics: Affluence and rising income, technology, job creation, quality of life and well-being, culture, energy price and cost, and energy accessibility and affordability.	[65,66]
		2. Transport or commuter modal choices (driving behavior and pattern) • Socio-psychological or attitudinal factors: Speed, convenience, flexibility, and time reliability of the alternative transport mode • Low carbon factors: Knowledge, and habit • Administrative policies: Driving restrictions, accessible and reliable public transport, and multi-level road planning	[4,60,72,73]
		3. Occupant or household behavior • Demographic characteristics: Level of education, family size, and the age of occupants • Socioeconomic factors: Household income level, household energy use, building quality, and energy-saving behavior of family members • Low carbon behavior: Values, knowledge, attitude, and lifestyle	[67–69]
		4. Consumer willingness to pay for low carbon products • Demographic characteristics: Gender, age, occupation economic situation, income, and education level • Personal values and attitude: Environmental awareness of environmental pollutions • Perception: Low carbon perception, and properties • Environmental knowledge, information, and situational factors: the degree of understanding acceptability, credibility, attitudes towards purchasing low carbon products, economic incentives, reference groups, social norms, perceived behavior control, propaganda guide, and price	[70,71]

The literature on low carbon pilots and sub-national application of the LCC concept shows that there are different policy instruments of various cities [8,81], based on the historical development function of the city and the focus of LC policies [35,83]. Therefore, the economy and industry interventions incorporate five conclusive pathways (see Table 2): (1) Energy efficiency (EE) upgrade or elimination of energy inefficiency industrial capacity; (2) developing strategic emerging industries focused on technology innovation and the service sector; (3) augmenting energy-efficient capacity of new industrial developments; and (4) the promotion of the circular economy concept buttressed by the low carbon ecological park. Other LCE concepts have also emerged in recent times, which suggests that cities are taking a more holistic approach to attaining its carbon emissions targets. These include low carbon ports (in Qingdao, Yantian, Caofeidian, Tianjin, and Ningbo) [84,85], low carbon food production [86], and low carbon tourism (in Zaozhuang, Shandong, and Leshan) [87].

Cities have made concerted efforts to assist heavy industrial sectors, particularly those plagued by excess capacity to pursue interventions that encourage the closure or upgrade of less energy-efficient industries (such as textiles, energy, heavy metals, coal and gas, cement, paper, automotive, steel, and consumer goods), that facilitate mergers and reorganization, as well as continue to strengthen the unflinching enforcement of environmental regimes [23,80,88]. Some scholars and industrialists have speculated that adopting low carbon policies such as upgrading or closing inefficient industries can affect business-as-usual and impede economic development. For example, Tao et al. [79] found that enterprises in Qingdao perceive low carbon strategies as unaffordable or a premature concept. However, Zhang et al. [40] found that increasing LC policies has not reduced economic growth as anticipated. A study by Shen et al. [12] in Beijing indicated that LCC has fostered green industries and brought impressive quality improvements, including structural change, and increased employment. Therefore, they suggest that in the long-term, enhancing EE is fundamental towards achieving both sustainable economic growth and environmental outcomes.

The injection of foreign direct investment and technical knowledge has resulted in the diversification of industries, shifting from the dominant manufacturing to emerging tertiary (service) and quaternary industries [1,43,79,89,90]. For example, Li et al. [84] highlights that the city of Wuxi has grown into the most significant production and export hub of the photovoltaic industry in China, where manufacturing and related industries are clustered. Meanwhile, Hangzhou development plans of strategic emerging industries and highlights the importance of research and development investments, cleaner production and circular economy. Liu et al. [35] believe that given that LCC pilots are being constructed in greenfield development, opportunities exist to integrate these systems from the outset to prevent carbon lock-in and expensive retrofitting. For instance, they evidenced that Binhai New Town, since its initiation, established an industrial system characterized by LCE, mainly focusing on wind energy production, enterprises, and improving the service industry. Several scholars consider these emerging industries as disruptive technological innovation [76]. This is because, they upgrade the urban industrial structure to provide a diverse range of industries, new markets and value networks that are conducive to energy savings, replicability, and industrial integration [89]. Supporting this assertion is the study of Gu et al. [91], which involved 132 LC enterprises in Liaoning. The study indicated that a high level of innovation in both technology and marketing has a positive influence on performance, while an external partnership may alter performance innovation. They also contend that merely deploying a high level of innovation orientation does not always yield an economic return on investment; therefore, improvement in knowledge as well as streamlining LC commitments throughout the entire management and supply chain will provide a more wide-reaching impact.

Circular economy pilot projects have been actively promoted at different scales (city-region, industrial park, and enterprise), bolstered by the circular economy strategic plan (2013–2020) [35,58,92]. Cities such as Guiyang [93] are vigorously developing a circular economy as an effective restorative strategy to achieve a high level of resource utilization, improve the efficiency of materials, industrial symbiosis, low waste and energy consumption, and the promotion of renewable energy [35,81,94]. A recent analysis from Dong et al. [95] found that the transition to a circular economy could reduce carbon emission in cities (3944.05 and 2347.88 thousand tCO_2/yr in Jinan and Liuzhou respectively), make goods and services more affordable for citizens, and reduce air pollutions. With the promotion of circular economy, many cities have initiated the construction of low carbon industrial parks, which are considered essential communities for promoting sustainability [96]. City-regions have made great strides in incorporating a wide variety of strategies. For example, the Shanghai Jinqiao Economic and Technological Development Zone focuses on automobiles, information and communication technology (ICT), household electrical appliances, biomedicine, and the food industry. Moreover, the Nanchang National High-tech Industrial Development Zone concentrated on biomedicine, photovoltaics, aviation, new materials, and electronic information; while the Luoyang National New and High Tech Industry Development Zone centers on biomedicine, new materials, and production of intelligent equipment [97].

Table 2. Integration principle: Economic dimensions of the China LCC initiative.

Sub-Dimensions	Components	Components in the Literature	Reference(s)
Economic	Industries and economy	1. Energy-efficient upgrade or elimination of energy inefficiency industrial capacity: • Textiles, energy, heavy metals, coal and gas, cement, paper, automotive, steel, and consumer goods • Eliminating outdated technology • Enforcement	[23,80,88]
		2. Developing strategic emerging industries focused on technology innovation capacity and the service sector • Environmental stewardship and EE, new energy, energy storage, ICT, biotechnology, high-end/technology manufacturing, smart energy vehicles, high-end technology and smart materials, photovoltaic industry, high-end service industry, and energy-saving agriculture machinery. • Services sectors (modern logistics, tourism exhibitions, financials, business, software, ICT, trade, and shipping logistics design, consultancy, and the creative industry). • Research, education, and development investments	[1,43,76,79,89–91]
		3. Augmenting energy-efficient capacity of new industrial developments	
		4. Promotion of the circular economy concept • Recycling utilization of useful resources, energy-conserving renovation of old buildings, recycling inter-regional industry system, and reuse of agricultural by-products and waste	[35,81,94,95,97]
		• Low carbon ecological park: Information industry, modern services, automobiles, household electrical appliances, biomedicine, food industry, photovoltaics, aviation, new materials, electronic information, biomedicine, energy conservation and environmental protection, and intelligent equipment manufacturing	[96,97]
		5. Market mechanisms • Incentives: Subsidies, clean development mechanisms, government allowances, discounted interest rates, and tax reduction	[35,80]
	Other industries	6. Low carbon ports	[84,85]
		7. Low carbon food production	[86]
		8. Low carbon tourism	[87]

The literature on LCE also emphasizes the need for a mix of "carrot" market-oriented mechanisms such as incentives, subsidies and clean development mechanism [80] that encourage enterprises to expedite the upgradation process and attract foreign direct investment (FDI). For example, the city government of Hangzhou provides incentives like government allowance, discounted interest rate, and tax reduction to prominent enterprises to attract them to the city [35].

The environmental dimension of LCC incorporates the buildings, transportation and mobility, energy, infrastructure, low carbon urban form, and climate resilience (see Table 3). Some of these components can be interwoven with economic dimensions, given their contribution to the local economy, while they have an adversarial effect with the natural environment.

In China, the building sector accounts for approximately 28% of total primary energy consumption [35] and 30% of GHG emissions [98]. Estimates suggest that 20 billion m^2 of housing need to be constructed by 2020, with an estimated 40% of 2030 building stock yet to be constructed, which could substantially increase energy use by 40% [99]. This provides an opportunity for implementing LC policies in the building industry, which can yield substantial direct and indirect benefits to the environment, society, and the economy [81,100]. Increasing strands of research on the building sector have revealed eight common strategies, incorporating operational and embodied energy, that are common interventions of pilot cities and provinces [8,44,83,100,101]. These include: (1) Introducing energy efficiency in new buildings to improve building energy-savings; (2) establishing mandatory green building; (3) strengthening energy conservation for existing energy-inefficient buildings through large-scale retrofit and renovation; (4) renewable energy integration in building systems; (5) support research and development (R&D) and the use of vital energy-saving building materials; (6) accelerating building energy labeling to encourage appropriate technologies; (7) providing market-based incentives to developers and consumers to invests in and purchase energy-conserving, low carbon buildings; and (8) building conservation standards and regulations, and compliance monitoring.

The adoption of green buildings is a central goal in the 13th FYP, with established goals to increase green buildings in new construction to 50% by 2020 towards attaining 28% penetration target by 2030 [102]. During this period, it is projected that China requires USD 250 billion in investments for energy-saving, institutional coherence and policy for large-scale retrofit, construction of green buildings, and energy efficiency of new buildings to ensure mandatory building energy-saving standards [103]. To accelerate the process, cities are adapting by establishing regulations and mandatory standards, clear guidelines, policies, economic incentives, technical assistance, and incremental support to eliminate obstacles that hinder the implementation of low carbon buildings [98]. Mature cities such as Shanghai and Beijing have rolled out large-scale retrofit programs to achieve co-benefits of more efficient buildings [104]. Even though the initial costs of energy-efficient retrofit present a considerable impediment to deployment, robust financing mechanisms (e.g., subsidies, grants, and incentives) have been used to overcome these hurdles to unlock both the direct economic savings and the wide-ranging benefits [105]. On another front, developing and selecting appropriate low carbon technology for buildings (through the building life cycle) [106] is a vital decision-making task to realize an optimal reduction in GHG emissions, employment generation and the overall sustainability of the development [107]. However, not much LCC studies have explored these options.

The transportation sector is one of the fastest-growing consumers of energy from fossil fuel and producer of GHGs in Chinese cities [108]. This stems from the growth and over-reliance on private motor vehicles, which in 2014 reached 154 million and is estimated to soar to 200 million by 2020 [109]. As of 2012, transport accounted for approximately 15.6% of total final energy use [33]. Municipal governments are already showing ingenuity and ambition in low carbon urban transport options to reduce carbon emissions as illustrated by the proliferation of policy options encompassing four key policy areas with commonality in pilot cities.

Firstly, LCCs have actively promoted non-motorized transportation options, or green trips such as walking, cycling, and required infrastructure as a valuable strategy to facilitate clean and efficient modes of travel [33,43,44]. Over the past four years, private and government-owned bike-sharing systems in densely populated cities increased precipitously [110,111]. For instance, cities such as Beijing, Shanghai, Hangzhou, Xining, Wuhan, and Zhuzhou have established sustainability public bike-sharing systems to reduce vehicle miles travelled (VMT) [35,110]. With variation in the degree of success, the sustainability of the city's program is anchored on the multi-faceted roles of stakeholders (commuters, urban dwellers, tourists, and operators), biking infrastructure, ownership model, and safety [21]. In Hangzhou for example, the Urban Public Bicycle Sharing Program was launched in 2010, represented the first bicycle-sharing program in China, and most extensive government-led program globally (280,000 passengers daily and 70,000 public bicycles) [35]. A key feature is a triple-bottom-line partnership between the government, universities and private entities, as well as the management system to ensure continuous improvement and maintenance of the system [35].

Secondly, LCC seeks to improve and expand public transportation and infrastructures, encompassing a broad range of transport modes such as trains (subways, metro, and urban rail transit), buses (including bus rapid transit (BRT)), and water transportation [43]. Following ambits of the National Transit Metropolis Demonstration Project (2011), municipal governments have prioritized investment in public transport, integrating smart transportation systems and infrastructure and providing a quantum upgrade of services [33,35]. Owing to the urban space constraints and the relatively fixed urban layout, mature cities regard subways as an ideal approach for mass transportation [35]. Urban rail transits (subways) have been established in large cities such as Shanghai, Beijing, Nanjing, Guangzhou, Shenzhen, Hangzhou, and Tianjin, with other medium-sized cities like Xian, Changsha, and Dalian at nascent stages in their development [44]. To enhance the capacity and reliability of the conventional bus system, some cities (Guangzhou and Wuhan) have developed the BRT system, which has similar benefits as the urban rail, but at a lower construction and maintenance cost [33,44]. Furthermore, central and local governments have popularized new energy public transportation. An example is the project of 10 thousand vehicles in one hundred cities, which has been promoted by using hybrid energy-saving and clean fuel buses and taxis [44]. On another note, rapid urbanization has increased the volume of urban public transport modes. For illustration, in Shenzhen, this has caused a rapid increase in total carbon emissions from 0.70 Mt in 2005 to 1.74 Mt in 2015 [112]. However, current low-carbon urban public transit mode has caused a reduction in CO_2 emissions by only 0.21 Mt of (cumulative value, from 2005 to 2015) [112], and will keep rising without a peak before 2050 [74]. Meanwhile, evidence in Beijing indicates that a combination of four policy approaches (public transportation improvement, public bicycle, EE improvement, and electric vehicle development) can reduce carbon emissions by 43% or 4.3 Mt of CO_2 per year [9].

Thirdly, low carbon transport aims to reduce emissions from private vehicle use and urban logistics. Based on the literature, four approaches have been used to reduce emission from motorized vehicles and to strengthen road freight logistics. In the first approach, low carbon energy and technology vehicles and infrastructures, such as biofuels, electric and hybrid vehicles, e-mobility charging stations and infrastructures, and battery storage are actively advocated and are now dominating the urban landscape [113]. Supported by the Central Government's favorable policies and being a key area in the "Made in China 2025" industrial strategy, several tier-one cities are experimenting with infusing market incentives (e.g., subsidies) and restrictions (Beijing and Shanghai have excluded electric vehicles (EVs) from restrictions on the registration of new vehicles) to force EV take-up [35,114]. For new energy vehicles to achieve the target of 40% share of auto-sales by 2025, the Made in China Plan indicates that three fundamental facets need to be fulfilled: Technological innovations, public awareness, and government guidance and partnership with industries [115]. The second approach seeks to continuously elevate fuel economy standards (FES) of private vehicles and logistics [44]. The third strategy, the optimization of logistics operations performance (e.g., efficiency, productivity, and cost), seeks to resign supply chain network by utilization of physical processes and operational strategies to reduce carbon emissions and cost [43,116]. The proliferation of e-commerce has necessitated the development of logistics planning in pilot cities. Therefore, a well-planned logistics system is an ideal pursuit of eco-efficiency, which can balance economic and environmental efficiency, and plays a significant role in carbon emissions reduction [117]. The fourth approach adopts transport demand management (TDM) strategies that focus on reducing VMT [118]. To mitigate congestion and reasonably control car ownership, cities such as Shenzhen, Beijing, Shanghai, Changsha, and Dalian have implemented strict TDM measures. Chief among them are changing people's behavior, parking restrictions and fees, congestion charges, car and ride-sharing, bicycle-sharing, telecommuting, co-working spaces, pedestrian and bicycle lanes, and internet-hired taxi [4,33,35,73,118].

Finally, the optimization of the urban spatial structure is considered as a 'transportation-efficient development' that influences the distribution of built environment activities in a metropolitan area to reduce final services and increase energy efficiency [33,60]. The literature reveals that the LCC physical design has embraced the integration of land use and sustainable transportation relationships. This integration manifests connectivity and access to frequent transit services, short pedestrian and cycling trips, job/house balance, and transition-oriented development (TOD) [113] resulting in fewer trips, and increase in green trips and public transport [35,113]. Wang et al. [119] and Zhao et al. [108] suggested that established cities like Shanghai and Beijing have used urban grown management strategies such as smart growth and new town development to control urban expansion and reduce motorized travel.

In 2014, the energy structure was dominated by fossil fuels (90.8%), with the highest proportion (66%) attributed to coal consumption [14,75,120]. Concomitantly, the rising energy demand from the urban system and low levels of energy efficiency (33%) [121] necessitate low carbon energy optimization to improve hovering high energy dependency, increase energy supply security, and reduce GHG emissions [122]. Responding to these challenges, pilot provinces and cities have embarked on a substantial transformation of the urban energy system into a sustainable realm. This is geared towards meeting China's short and long-term goals of increasing the share of non-fossil fuel from 9.2% in 2014 to 15% and 20% in 2020 and 2030 respectively [40,57,123]. Although these projections are optimistic, it is still difficult to alter the ethos of coal and gas, which will contribute to 55% of the primary energy mix in 2050 [124]. As an alternative, studies have suggested that the exploitation of clean coal is a realistic choice in the short term, while the development of renewable energy sources should be a strategic choice to ensure long-term sustainability [75,120].

The sustainable exploitation of clean energy and energy efficiency are the critical twin pillars to realize an LC energy structure [123,125–127]. Clean energy technologies actively encouraged in pilot provinces and cities include both renewable and alternative energy technologies. Renewable energy technologies include solar energy, wind energy (small-scale wind generators), bio-energy, geothermal, hydropower, and tidal energy; alternative energy technologies comprises hydrogen fuel cells, cold-base methane, nuclear, natural gas, heat pump, carbon capture and storage, and microgrid [8,25,46,75,101,123,125,127–132]. These different clean energy technologies are developed and applied to diverse urban domains to ensure energy security, climate change mitigation, and local economic development. Energy storage technologies, which include thermal storage, batteries, and pumped hydro, adds flexibility to the grid, which enables renewable energy to generate power when they would otherwise be unable to do so. It is an immature technology in China, which has restricted its practical and commercial applications [105]. However, policymakers have proposed the large scale expansion, and research and development of low-cost energy storage technology to support renewable energy integration, EV and microgrid development [13,75].

For instance, Baoding, a heavily industrial prefectural city, acts as an exemplary practice for the manufacture and deployment of clean and LC energy technologies [133]. Known as the "Electricity Valley of China", this city is renowned for its solar photovoltaic industry, wind, and energy storage [31,134], and has integrated these technologies into the urban system. Furthermore, the city has established networking on knowledge management and technology cooperation, investment in the export of energy products, embarking on capacity building in urban planning, and providing financial support and mechanisms such as support funds and tax incentives [127]. Other cities, such as Chongqing and Shenzhen, have focused on the manufacture of wind, solar photovoltaic, natural gas, and utilization of the [8,135,136]; Kunming, Xiamen, and Rizhao have also focused on solar photovoltaic, waste-to-energy, and heat pump [60]; while Beijing, Ganzhou, and Guangzhou have established no coal-burning zones in the downtown district [127].

Table 3. Integration principles: Environmental dimensions of a low carbon city.

Sub-Dimensions	Components	Strategies Identified in the Literature	References
Environment	Buildings	1. Energy efficiency in new buildings to improve building energy-savings	[8,83]
		2. Establishing mandatory green building	[8,83]
		3. Large-scale retrofit/refurbishment, and adaptive reuse	[8,83,104]
		4. Renewable energy integration in building systems (net-zero and net-positive energy buildings)	

Table 3. *Cont.*

Sub-Dimensions	Components	Strategies Identified in the Literature	References
		5. Energy-saving building materials	[106]
		6. Building energy labeling to encourage appropriate technologies	[106]
		7. Market-based incentives to developers and consumers to invests in and purchase energy-conserving, low carbon buildings	
		8. Building conservation standards and regulations	[98]
	Transport and mobility	1. Non-motorized transportation options, or green trips • Walking, cycling network, and the provision of infrastructure • Bike-sharing systems (public and private)	[21,33,35,43,44,110]
		2. Improve and expand access to public transportation and infrastructures • Trains (subways, metro, and urban rail transit) • Buses, water transportation, and bus rapid transit (BRT) • Smart transportation systems and infrastructure • Provide affordable (subsidized) and accessible public transport • New energy public transportation	[33,35,43,44,114]
		3. Reduce emissions from private vehicle use and urban logistics • Low carbon energy and technology vehicles and infrastructures, such as biofuels, EVs (e-bike, e-bicycle, e-car, e-bus, e-truck, e-scooter, and e-bus), hybrid cars (BEVs, HEVs, FCEVs, and PHEVs), e-mobility charging stations and infrastructures, and battery storage • Elevate fuel economy standards (FES) of private vehicles and logistics • Optimization of logistics operations performance (e.g., efficiency, productivity, and cost) • Transport demand management (TDM) strategies: Parking restrictions and fees, congestion charges, car and ride-sharing, bicycle-sharing, telecommuting, co-working spaces, pedestrian and bicycle lanes, internet-hired taxi, traffic calming, and BRT • Raising parking fees and limited parking supply • Driving restrictions (license-plate number restriction, license-plate lottery, and license-plate auction) • Infusing market incentives	[4,33,35,44,73,113–115,118]

Table 3. *Cont.*

Sub-Dimensions	Components	Strategies Identified in the Literature	References
		4. Optimization of urban spatial structure • Transition-oriented development (TOD)	[33,35,60,113]
	Energy	1. Clean energy technologies • Renewable energy: Solar energy (thermal and PV), wind energy (small-scale wind generators), geothermal, hydropower, and tidal energy • Alternative energy: Fuel substitution, bio-energy, hydrogen fuel cells, cold-base methane, nuclear, hydrogen fuel cells, natural gas, heat pump, carbon capture and storage, and microgrid. Cogeneration or combined heat and power • Energy storage technologies: Thermal storage, batteries, and pumped hydro	[8,13,25,31,46,75,101,105,123,125,127–134]
		2. Energy efficiency improvements • Energy efficient technologies include co-generation or combined heat and power (CHP) systems, waste heat recovery, integrated gasification combined cycle (IGCC), smart grid, visual display monitoring technologies, fiber optics for data acquisition, carbon capture and storage (CCS), and boiler retrofit.	[8,15,101,127]
		• Energy management practices include system operation optimization, motor energy-saving, energy audit and retrofit, fuel substitutions, heating and cooling services with efficient equipment, adjustments in use patterns and proper maintenance, lighting (using efficient light-bulbs, changing types of light sources, maximum use of natural lighting, and behavioral changes), and energy labeling.	
	Low carbon urban form	1. Renewal and revitalization (e.g., Greenfield protection, cautiously redevelop brownfield, infill, and grey field sites) 2. Compaction, density and scale, and control of urban sprawl (by establishing urban growth boundaries) 3. Mixed land use development, housing-job proximity 4. Provision of amenities and urban services 5. Small-size urban block 6. Passive solar design, e.g., solar orientation (day-lighting), solar shading, UHI, ventilation, insulation, windows, and glazing 7. Underground volume rate 8. Urban ecological spaces and carbon sinks (e.g., urban space, green infrastructure-green roof, native plant species, and urban forestry) 9. Blue infrastructure (e.g., wetlands and lakes) 10. Preservation and conservation of historical heritage and traditional culture	[36,50,83,108,113,137–146]

Table 3. *Cont.*

Sub-Dimensions	Components	Strategies Identified in the Literature	References
	Infrastructure	1. Water supply system: Advanced water treatment methods (e.g., desalination), re-evaluate raw water intake strategies to minimize energy use requirements, promote water demand management through price or non-price measures, water conservation management, and advanced water supply systems for saving water and energy efficiency	[2,11,33,83,147,148]
		2. Sewage treatment system: Decentralized treatment systems, low-energy anaerobic treatment, minimize carbon emissions from sludge disposal, grey water recycles and treatment, and construction of the stormwater and sewage diversion system	[8,33,43,148–150]
		3. Low impact development: Planning practices (e.g., green roof, bioswales, rainwater harvesting, constructed wetlands, permeable paving/streets, green roads, and retention and detention ponds), and planning principles (e.g., vegetation conservation design and curtail land interference)	[33,83,148,150]
		4. Waste management: Waste-to-energy, integrated sustainable waste management approach based on circular economy development, reduce–reuse–recycle–compost–dispose	[8,11,33,50,93,105,106]
		5. Lighting: Light-emitting diode (LED) intelligent system for street and outdoor lighting	[11,150]
	Adaptation and resilience	1. Integrate climate risk management into climate-smart investment to increase adaptive capacity: Improve agriculture, urban forestry, urban coastlines, water adaptation ability, and hazard mitigation	[30,33,50,56,58,151]
Governance	Type of governance	1. Top-down technocrat approach	[8,58]

BEVs: Battery electric vehicles; HEVs: Hybrid electric vehicles; FCEVs: Fuel cell electric vehicles; and PHEVs: Plug-in hybrid electric vehicles.

Energy efficiency improvements predominantly emphasize available technologies and adopting better energy management practices [8,15,101,127]. Energy-efficient technologies include co-generation or combined heat and power (CHP) systems, waste heat recovery, integrated gasification combined cycle (IGCC), smart grid, visual display monitoring technologies, fiber optics for data acquisition, carbon capture and storage (CCS), and boiler retrofit. Meanwhile, the energy management practices include system operation optimization, motor energy-saving, energy audit and retrofit, fuel substitutions, heating and cooling services with efficient equipment, adjustments in use patterns and proper maintenance, lighting, and energy labeling.

New strands of research show that the low carbon urban form characteristics are necessary elements of the sustainability strategy for urban regeneration and new urban development [137]. These characteristics include renewal and revitalization (e.g., greenfield protection, redevelop brownfield, infill, and grey field sites), compaction, density and scale, control of urban sprawl (by establishing urban growth boundaries), mixed land use development, housing-job proximity, provision of amenities and urban services, size of urban block, passive solar design, underground volume rate, urban ecological spaces and carbon sinks (e.g., urban space, green infrastructure-green roof, native plant species, and urban forestry), blue infrastructure (e.g., wetlands and lakes), and the preservation and conservation of historical heritage and traditional culture [36,50,83,108,113,137–146]. When done correctly, these factors can have significant impacts such as enhancing energy production and performance, reducing the need for mobility, reducing GHG emissions increasing economic and social vitality, and creating and preserving urban green space and cultural heritage [36,138,142],. For example, a study by Wang et al. [111] in Xining shows that approximately 30% of the power consumption and CO_2 emissions can be decreased with the optimization of the urban spatial structure. For this reason, cities such as Shanghai, Beijing, and Shenzhen have established mixed land-use guidelines and low carbon planning and design standards in typical functional areas [83,146]. Meanwhile, Hangzhou encourages comprehensive land-use strategies to achieve low carbon development that includes ecological land conservation, compact development, and urban sprawl control [50]. Although carbon sequestration is one of the strategic targets for reducing carbon emission in LCCs, urban green infrastructure in Chinese cities has a relatively low carbon density [138]. Therefore, cities such as Tianjin and Shenzhen have incorporated a forestry carbon sink, ecological system protection and restoration, and the development of green parks to increase afforestation and recovery of the marine ecosystem [127].

Infrastructure is the lifeline of the city and considered a key crux for climate change solutions or low carbon technology options [96]. The ability of infrastructure assets to facilitate the transition to an LCC has to be explored from the cradle-to-grave perspective, with a long lifespan to curb a lock-in of high carbon pathway [105]. Strategies to reduce carbon emissions from the municipal infrastructure are complex and interconnected [33] with varied level of adoption. The water supply system is intrinsically linked to energy use and epitomizes an untapped potential for further reduction in GHG emissions. Innovative ideas in low carbon cites include advanced water treatment methods (e.g., desalination) to minimize energy use, re-evaluation of raw water intake strategies to minimize energy use requirements, promotion of water demand management through price or non-price measures, water conservation management, and advanced water supply technology, processes, materials, and equipment for saving water and energy efficiency [2,11,33,83,147,148]. Meanwhile, low carbon emission pathways in sewage treatment systems can be offset by adopting strategies such as decentralized treatment systems as coverage expands to peri-urban areas, low-energy anaerobic treatment, minimization of carbon emissions from sludge disposal, grey water recycle and treatment, and the construction of rainwater and sewage diversion system [8,33,43,148–150]. Low impact development assists in achieving the sustainable site design and protects water quality through the promotion of appropriate actions such as planning practices (e.g., green roof, bioswales, rainwater harvesting, constructed wetlands, permeable paving, and retention and detention ponds) and planning principles (e.g., vegetation conservation design and curtail land interference) [33,83,148,150]. Low carbon waste management requires waste material to be continually cycled through the economy, while disposal is minimized. Climate-smart waste management strategies comprises waste-to-energy, integrated sustainable waste management approach based on circular economy development, and reduce–reuse–recycle–compost–dispose [8,11,33,50,77,93,105,106]. Furthermore, as an emission cutting and cost-effective technology, the light-emitting diode (LED) intelligent system for street and outdoor lighting is now broadly being deployed by pilot cities [11,150].

Regarding adaptation and resilience, research shows that the decrease in carbon emission is not sufficient to halt the effects of climate change. Therefore, given China's high vulnerability to natural hazards [33], LCCs such as Beijing, Shanghai, Tianjin, and Chongqing have adjusted and incorporated adaptation strategies in their low carbon plans [50]. This is done to build urban resilience in response to climatic stimuli [56]. Therefore, the urgent development and implementation of balanced adaptation strategies in these cities integrate climate risk management into climate-smart investment to increase the cities' adaptive capacities and improve agriculture, urban forestry, urban coastlines, water adaptation ability, and hazard mitigation [30,151]. With this being said, most of the strategies and discussions focus on mitigation [58]; and there is a lack of cohesion between mitigation and adaptation strategies, which can lead to maladaptation [30,50].

The process of decentralization in China has provided the conduit for the rationalization of the intricate interactions between the central government, local government, and the inclusion of urban stakeholders in developing low carbon strategies [38,58,62,63,108,152–156]. Recent studies on LCC development have illustrated that the dominance of the top-down technocrat approach fails to account for the interrelationship between stakeholders in the planning of LCC projects. This has resulted in substantial implementation gaps [23,58,62,154,157], as well as partially delay the development of the LCC agenda [152]. Due to this contradiction, the NRDC hopes to implement pilot programs and summarize experiences from a bottom-up mechanism, to take advantage of the consensus-building among diverse stakeholders [8,58].

3.2. Implementing Principle

The implementation of LCC is a complex process and entails governance, planning mechanisms, monitoring and evaluation, financing, and context and process (Table 4). Finance and investment are the core element of the implementation process and essential to nexus future climate change targets. It is projected that during the 13th five-year period (2016–2020), approximately 6.6 trillion RMB will be needed to implement LCC projects for EE and green buildings, sustainable transportation, and clean and renewable energy [158]. With the share size of funding needed, exigent investment backing is required to scale-up the deployment of low carbon pilot initiatives. In the literature, funding is recognized as a significant barrier to the successful implementation of LCC projects [157], but there are heterogeneous sources of funding that have been identified. The government plays an instrumental role through central and local budgetary allocations, R&D, direct subsidies, incentive funds, grants, demonstration projects, taxation, and credit enhancement measures [16,30,62,94,115,159]. Further, they have also provided the appropriate resource mobilization such as establishing ideal institutional setting, defining standards, establishing viable financial policy incentives, and a transaction framework, to overcome barriers for private investments. Low carbon financing has been leveraged by other non-government funding sources such as public and international market (foreign direct investment, stock market, and carbon market), commercial and inter-bank finance (domestic loans, debt finance, corporate bonds, and green credit), private finance (venture capital, private equity, and corporate finance), and international assistant programs [159,160]. The literature has pinpointed that pilot cities have utilized financing models such as the public–private-partnership to mobilize financial resources, technologies, and technical expertise of the private sector for the construction of public sector projects [159]. Furthermore, market-based policy instruments, such as the carbon trading market (CTM) have been introduced, as a key pillar to manage GHG emission and achieve carbon intensity targets more cost-effectively [158,161]. Since 2014, the NDRC has initiated the CTM pilot in five cities (Shanghai, Beijing, Shenzhen, Chongqing, and Tianjin) and two provinces (Guangdong and Hubei) [161–163]. This is done to encourage the operational efficiency of more than 1900 industries and enterprises, and incentivize the deployment of existing and innovative disruptive renewable energy technologies.

Table 4. Implementing components of the China LCC initiative.

Sub-Dimensions	Components	Strategies Identified in the Literature	References
Finance and investment		1. Sources of funds • Central and local budgetary allocations: Direct subsidies, incentive funds, grants, demonstration projects, taxation, and credit enhancement measures • Resource mobilization and enabling environment	[16,30,62,94,115,159]

Table 4. *Cont.*

Sub-Dimensions	Components	Strategies Identified in the Literature	References
		2. Non-government funding sources • Public and international market (foreign direct investment, stock market, and carbon market) • Commercial and inter-bank finance (domestic loans, debt finance, corporate bonds, and green credit) • Private finance (venture capital, private equity, and corporate finance) • International assistant programs	[159,160]
		3. Financing models • Public–private-partnership (PPP)	[159]
		4. Market-based policy instruments • Carbon trading market (CTM)	[158,161–163]
Planning mechanisms	Low carbon action plans	1. Low carbon development and implementation plan 2. GHG emission inventory, which is used to establish the carbon reduction target	[127]
	Policies, strategies and actions	■ Define the concrete cross-sectoral reduction strategies	[127]
	Legislations, regulations and urban guidelines	1. Land-use zoning codes, building codes, tax incentives, parking requirements, solar easement, fuel economy standards, energy labeling standards, and green building rating systems. Urban design guidelines 2. Specific regulations on energy savings conservation 3. Air pollution prevention control legislation 4. Energy rating systems	[22,33,61,105,153,164]
Monitoring and evaluation	KPI/Indicators	1. Performance evaluation: (target responsibility system) • Energy savings • Carbon intensity • Renewable energy concentration • Forest coverage	[165]
Participatory governance	Management and institutional setting	1. Political commitment and leadership 2. Integration of low carbon strategies in existing strategic policies 3. Inter-sectoral and inter-jurisdictional collaboration	[33,50,166]
Context and Process	Pilot and Demonstration	1. Pilot projects	[8]

Pilot cities and provinces use various planning mechanisms as strategic tools that enhance the planning and implementation of LCC [37]. The literature has identified three main types of mechanisms: Low carbon action plans, policies and strategies (actions), and legislation, regulations, and guidelines. The formulation of low carbon development and an implementation plan is a fundamental requirement for the pilot cities and provinces. The plan provides the GHG emission inventory, which is used to establish a carbon reduction target and define the concrete cross-sectoral reduction strategies [50]. However, there is a substantial gap between the planning and implementation, because of a lack of integrated framework, and principles and guidelines to connect and guide local jurisdictions on turning the plan into action [127]. In their research, Wang et al. [127] indicate that the rationale for this is that some pilot provinces and cities utilize low carbon strategies and guidelines formulated by the central government, without tailoring to fit the local conditions. Additionally, the implementation is supported by deploying several central and local legislation, regulations, and urban development guideline tools to assist city stakeholders and decision-makers in understanding and mainstreaming them in policies and actions. These include land-use zoning codes, building codes, tax incentives, parking requirements, solar easement, market liberalization, fuel economy standards, energy labeling standards, and green building rating systems [33,61,105,153]. For example, energy rating systems have been used in the Shanghai Hongqiao Central Business District to enhance the sustainability of construction projects, and as a marketing tool to attract investment and new tenants [157]. However, to achieve optimal multiple benefits, the most practical approach is to adopt and combine several tools administered at the various governance levels. For instance, in 2018, the Guangdong Provincial government published their low carbon urban design and development guidelines, which provide the right impetus for effective implementation targeting macro-systems, spatial elements, and urban management [167]. They have also actively promoted the deployment of low carbon product certification and labeling. As it relates to legislation and regulations, Shanghai, Beijing, and Shandong have enacted specific regulations on energy savings for industrial structure optimization [164], while air pollution prevention control legislation has been established in Beijing, Guangzhou, and Shanghai [22].

Tracking the progress of the action plans and successfully achieving low carbon emission targets requires the development of performance systems for monitoring, evaluating, and reporting (MER). To date, however, there is a lack of a structured and comprehensive institutional framework for MER city's transition [165]. According to Price et al. [168], the current evaluation system and indicators are based on the NDRC LCC development guidelines, with technical indicators that are difficult to assess, aggregate, and determine if a city is low carbon or not. However, the provincial governments have developed performance evaluation for energy savings, carbon intensity, renewable energy concentration, and forest coverage, which binds local officials' professional promotion to reduction targets [165]. The lack of comprehensive national, provincial, and city evaluation protocols has led to many studies that have developed and evaluated the progress of LCC nationally [169,170], provincially [171,172], and city-wide [10,118,148,173]. These studies indicate that there is a need for a scientifically rigorous MER system, which is locally specific, incorporates multiple stakeholders in the planning process, and covers not only technology, economic, and environmental parameters, but also social equity. This will ensure that the outcome of LCC planning is mutually beneficial and that the human-centered qualitative index is captured to inculcate inclusive planning. This underpins the need for regular engagement of not only primary stakeholders but also citizens, who are affected by the planning decisions.

Participatory governance is an integral part of the implementation process in delivering LCC and encompasses ongoing political support and commitment, fostering inter-sectoral and inter-jurisdictional cooperation, management and institutions, capacity building, education and awareness, and citizen engagement. By becoming a pilot province or city, local policymakers reinforce their strong political commitment to ensure the successful design, implementation, and monitoring (program delivery) at the highest level. Political commitment and leadership are driving forces that stimulate management and institutional settings. While the central government, through the NDRC, establishes an enabling environment, municipal authorities in China have direct jurisdictional authority and autonomy over the planning and coordination of land use and economic decision-making, therefore, deciding and implementing LCC falls within their scope [33]. However, LCD policies are often conceived as an external dichotomy but should be integrated into the urban system components, as well as existing strategic policies in the cities, e.g., master plan, transport plan, and local economic development plan [50]. A study by Li et al. [50] has noted the lack of horizontal coordination and collaboration between various departments in local administration, which is considered a significant barrier to implementation in Chinese LCC movement. This is because there are continuous silo and disaggregation of roles and responsibilities. Consequently, transparent management and institutional structure coupled with the apportionment of responsibilities for the implementation of actions are requirements for the successful and sustainable implementation of the LCC. This requires not only inter-sectoral vertical and horizontal cooperation between various departments in central and local administrations (inter-departmental planning, and inter-sectoral institutional coordination), but also inter-jurisdictional collaboration through international "Sino" relationships (transnational exporting) [166]. "Sino" cooperation has become a pragmatic and practical imperative of LCC in China, as they possess the technical capacity to unlock low carbon growth. These low carbon plans are associated with not only local NDRC programs, but also with international programs such as the C40 group and WWF [50].

In reviewing the literature, no empirical research or case studies have examined issues related to capacity building, education, and public awareness were found. However, these are all critical parts of the planning and implementation process. Capacity building for local policy and decision-makers is imperative to develop a thorough understanding of LCD [174]. Information acquisition, education, and awareness are essential means to keep stakeholders informed and motivated about the nature of climate change problems, the interventions being undertaken by the government, and help to them devise an appropriate response to lifestyle and behavioral change [41]. Li et al. [6] found that low carbon plans and numerous central government documents in China (e.g., National New-type Urbanization Plan 2014–2020, National Congress) have strategies for public engagement and participation. However, the planning process for creating the plan still utilize a technocratic rationalize planning framework, ignoring public and enterprises. Wang et al. [165] showed that there was an insufficient interaction between the municipal government and enterprises in the development process of policies in the low carbon transition. This is an important tenant of sustainability, as it will enhance their awareness of low carbon technologies, which is indispensable to social and intransigent reform such as in lifestyle changes, and expand their perception of active engagement and participation [157].

3.3. *Equity*

The equity principles of China's LCC are summarized in Table 5.

In a market-led economy, some stakeholders are driven by bottom-line figures or have economic development interests (also called 'GDPism' and growth fetishism), competitiveness, and maximization of return on investment, while others seek socio-spatial modernization, urban environmental regeneration, and non-finance performance [66,108,111,129,175]. Several studies have agreed that the successful implementation of LCC projects, necessitates the willingness of the relevant stakeholders to redefine or coordinate their priorities and actions [57] and balance their interests [150], views, and goals to achieve the LCC objectives [62,63]. In Shenzhen International LCC, for example, Zhan and Jong [159] asserted that the unique "A + 1 + 2 + N" management system provided the "comprehensive service platform" for balancing stakeholders interests. This dynamic structure creates a four-tier hierarchical system, which outlines the dominant and synergistic roles of local government, district governments, established development companies, and the investment role of the private real estate developers.

The literature reveals that a multitude of stakeholders are involved in the LCC planning process. However, there is skewed participation and lack of deliberative opportunities; some actors were excluded from the collaborative process [153]. The stakeholders were classified under three groups of actor constellations [8,159], with their input occurring at five stages (Figure 6). Actors in the LCC development process include internal stakeholders, key or primary stakeholders, and lateral or secondary stakeholders.

The internal stakeholders include decision-makers, regeneration implementers (real estate developers), and experts. They have high interest and hold a substantial amount of power and influence over the construction of the LCC. Decision-makers include the central and local governments, as well as their departments, agencies, and ministries. At a strategic level, the central government, through the NRDC, is the central planning agency that provides the broad vision and support for LCC development [8,127] and issues comprehensive decarbonization targets. The municipal governments are at the forefront of experimentation in LCC [153] and are involved at all stages in the planning process [58,66]. Their extensive array of functions include coordinating the development of the integrated LCC blueprint, which consists of various strategic actions in different sectors and setting of targets aligned to the national targets [35]. Further studies in Shenzhen illustrates that the municipal government is also responsible for developing innovative management mechanisms, land acquisition, investment promotions, and facilitating engagement among the stakeholders [63,159]. Furthermore, the municipal authority establishes a steering committee, which is composed of national ministries, commissions, the mayor, local agencies who are responsible for overseeing the progress of the LLC, yet they exert at a distance [159].

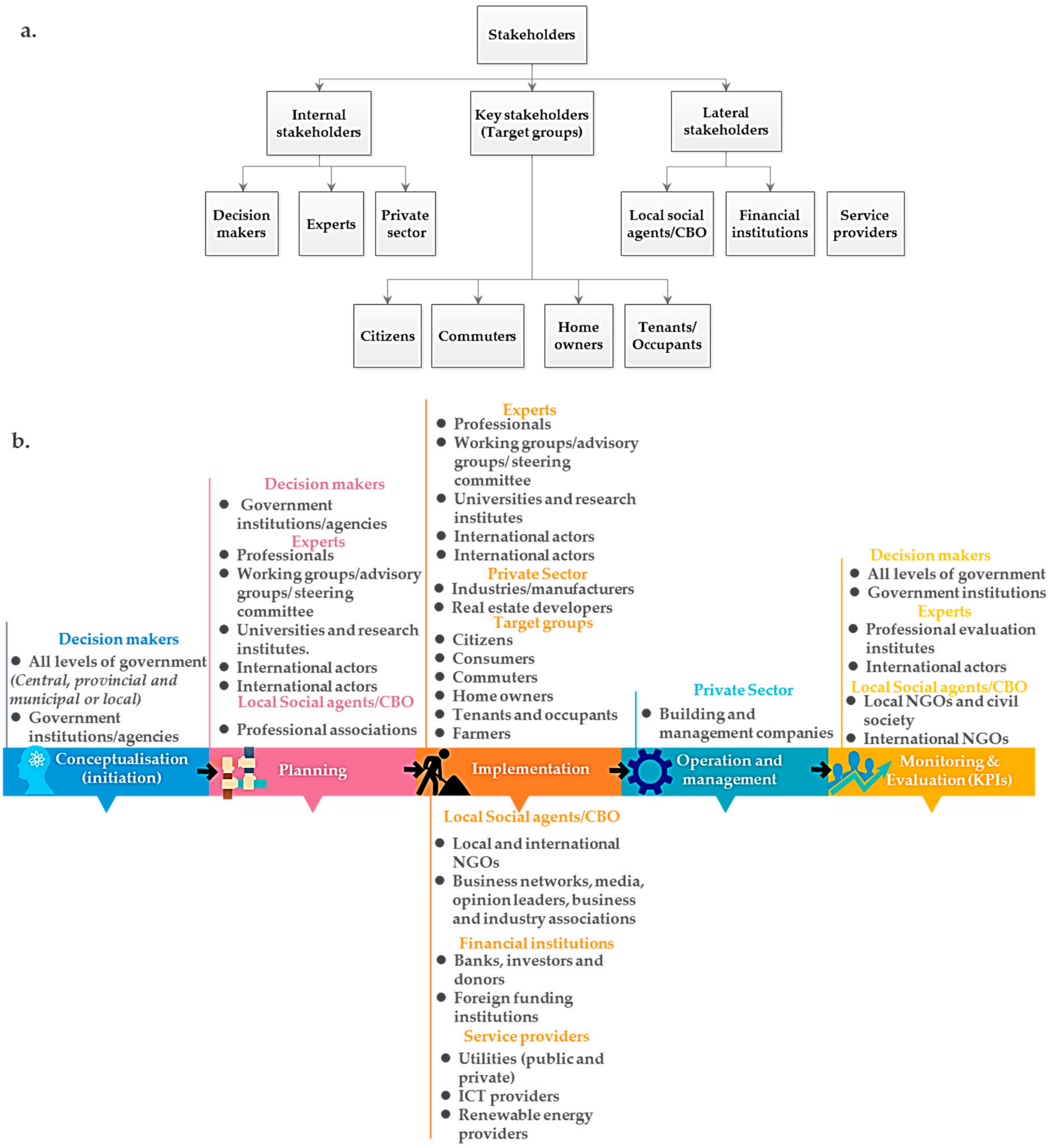

Figure 6. Categorization of (**a**) stakeholders and their (**b**) involvement in the LCC development process.

Designing and implementing physical development materializes by the actions of private developers or local development corporations mostly invested by the government and international partners following a development application approval by the local government. Being a key stakeholder means that the local and district level construction companies are responsible for financing and investment, promoting investment, infrastructure development, operation, and management [63,159]. Their system-oriented need and vested interest are to deliver the best projects to meeting the spatial framework goals, establishing the low carbon business case, increasing the value of state-owned assets, ensuring the success of commercial projects, enhancing reputation, and maximizing the return on investment [159]. However, as Yang [98] and Zhang et al. [11] emphasized, the short-term economic development impetus that drives private real estate developers does not align with the need for the long-term development cycle of building low carbon communities. Experts are vital to the planning, implementation, and monitoring and evaluation of LCC. This group consists of a wide variety of actors, including planners, architects, engineers, project managers, building design and sustainability consultants, energy service companies (ESCOs), universities and research institutes, international actors, and professional evaluation institutes (green building institutes). Their roles generally entail preparation of the LCC "realistic" master plan that will be adopted by the developers, research and development, technical support, and ensure that LCC strategies and policies are integrated into the development plan. Further literature highlights the integral role being played by international actors who are partly involved in the master planning and implementation process. In Shenzhen, for example, Cheshmehzangi et al. [152] and Zhan et al. [159] underscore the involvement of Sino-foreign partnerships undertaking numerous substantive roles toward the realization of the LCC vision. These roles include: (1) Knowledge transfer by research collaboration hub between Chinese and international institutions (joint institutes); (2) technology transfer and technical support; (3) project-based participation in construction and delivery (carbon open platform and monitoring of carbon emissions); (4) providing support for advanced ICT; (5) green building demonstration; (6) regional development and communication; (7) developers for investment (limited capital agency and their regional management); and (8) engaging in the project planning.

The key stakeholder or target group refers to the intended beneficiaries of the LCC development and consists of the end-users (citizens, commuters, homeowners, and tenants/occupants). Their role is to obtain credibility and acceptance of the activities. The status quo of Chinese urban development is that citizen engagement is underemphasized, as their role in the planning and development of LLC is limited to the implementation phase. In Suzhou, Li et al. [6] found that citizen participation was limited in the decision-making and master planning process, but was substantially enhanced during the implementation phase. Here, they provide comments through push and pull engagement to publicize the plan and gain grass root support. In Shenzhen, Zhan et al. [159] observed a similar trend; however, residents provided land and property as investment resources, with their central interests, including increasing dividends and also improving their quality of life.

The secondary or intermediate stakeholder groups include a wide variety of actors such as local social agents, enterprises (industry and business sector), business associations and networks, financial institutions (banks, investors local and international, the public, donors, and international funding institutions), and utility service providers. Their roles include obtaining credibility and acceptance of their activities, and influence on the implementation of decisions. The empirical evidence that exists on the various actors in this actor constellation is limited. However, based on a textual analysis, they have varied interests in the development outcomes. In Suzhou and Shanghai, some studies [44,58,66] suggest that enterprises are essential players in the LCC in China, as they are the chief consumer of energy and their role is to apply technological innovations for sustainable energy system and commercialization. In Rizhao and Shenzhen, Huang et al. [176] suggest that enterprises act as intermediaries in the transition process as so-called "policy-industry dissonance" towards the development of solutions and their implementation. This study found that their interests in low carbon technological innovation are still low. However, their participation is highly dependent on incentives by decision-makers, as well as legislative requirements [66]. Meanwhile, the role of civil society such as NGOs, although underplayed, has been increasing in relation to environment governance [153] and being a bridge between government and public [58]. Studies in Shenzhen and Suzhou [58,63] have shown that local and international NGOs (e.g., World Resources Institute, Worldwide Fund for Nature, Global Environmental Institute, Friends of Nature, Global Village, and Green Earth Volunteers) provide crucial communicative and awareness functions to increase public consciousness, enhance climate management, promote EE, encourage the construction of green buildings, reforestation, and reduction of carbon emissions. Financial institutions and investors are creditors that provide financial support and land provision and needs to ensure return on investment [159], adequate profitability, the achievement of project goals of scope, time, cost, and quality. This emphasizes their importance as project stakeholders but they cannot intervene.

In the contemporary style of urbanization, megacities have refocused their development trajectory, placing less focus on social inclusion for new dwellers [177]. For example, Zhang et al. [11] illustrate this with the use of the ten one planet living (OPL) principles to examined low carbon communities in Tianjin and Shenzhen that encompass various green or low carbon strategies and technologies. However, the study found no were actions undertaken to achieve the principles of equity and fairness. The study concluded that this lack of comprehensive mechanism and focus would hinder the achievement of the LCC goals. Similar findings were found by Fu et al. [43] who analyzed the performance of low carbon, ecological-city, and conventional new towns in China. Cheshmehzangi et al. [152] posits that one reason for this dearth of social justice and inclusion issues is that the globalization and marketization impetus disregard the local context, giving high priority and value to economic maximization by creating neighborhoods for the elites. Therefore, China is now at a crossroads between pursuing the modernization and industrialization agenda and recalibrating the quality of life of the people. While the economic transition and urbanization rate has led to bourgeoning hypermodern megacities, it has also resulted in deteriorating social and income disparities, as well as social inequalities [17]. It has also resulted in an increasing spending power, which results in changing consumption patterns, ostentatious lifestyle, and consumer behavioral change among the upper echelon of society [62].

The planning and development of LCC can catalyze technological solutions as well as social harmony to ensure equal opportunities and reducing disparities [62]. These include the creation of employment opportunities in cutting high-tech industries. Moreover, achieving environmental justice and health equity through the polluter-pay-principle (control levels and polluters discharges) is used by the Ministry of Environmental Protection (MEP) [62] as an intervention for eliminating the effect of externalities [162], such as work productivity, health risks, and societal and environmental damages related to air pollutions [22,23]. This supports the consensus that citizens should have the equivalent opportunities, fairness, and rights to access public goods, including a clean environment, as proposed by Gao et al. [178] in Shanghai. Therefore, the implementation of LCC technologies, which reduces carbon emissions and other environmental pollution will ensure a reduction in health impacts.

China still has over 70 million people (10%) living below the poverty line [19,76], and having limited access to energy [23,62]. The objective of the Chinese government is to reduce absolute poverty to zero by 2020, which is an essential input for achieving the most sustainable development goals. Recent LCC policy initiatives, which are often overlooked, have targeted tackling the reduction of poverty. One of such initiatives, being championed by the National Energy Administration (NEA), is the deployment of solar photovoltaic as a tool for poverty reduction [132]. Furthermore, the energy cost to consumers in China is considerably low due to high subsidization policy of the Chinese government [92], and this has reduced the burden to the vulnerable households [179].

Table 5. Equity principles: Procedural, intergenerational, and intragenerational equity dimensions of LCC in China.

Sub-Dimensions	Components	Strategies Identified in the Literature	References
Procedural	Stakeholder participation	1. Involvement of a diverse range of interested parties in the entire decision-making process 2. Balancing stakeholders' interests	[6,8,10,38,57,58,63,66,127,150,152,153,156,159,175,181,182]
Intragenerational		1. Equality and disparities: Increased local job creation and income possibilities; improving the attractiveness and quality of the urban environment and urban design for the benefits of citizens, the economy and society as a whole; achieve environmental justice and health equity through the polluter-pay-principle; and affordable social housing 2. Need: Reduce fuel and energy poverty; and poverty prevention and alleviation (poverty rate) 3. Demand: Rights to access public goods (e.g., public open and green spaces); adequate service characteristic (time, location, quality, safety, aesthetics, and complex mobility needs) from the perspective of the potential user; access to public transportation options to public transit stops; and increasing the job-housing balance 4. Willingness-to-pay: Improve the cost-efficiency of the transportation of persons and goods; and reduce energy/electricity cost through subsidization.	[22,23,62,132,162,178,180]
Intergenerational		1. Short and medium temporal variation in targets • GHG reduction, energy intensity, forest coverage rates, and proportion of non-fossil fuel energy in the energy mix	[8,37,127,165,174,183,184]
Scalability and replicability		1. Transferability of viable "technological" solutions and innovative approaches • Promotion of joint urban development clusters • Living laboratory • Knowledge and technology transfer • Demonstration zone development	[7,24,33,79,157,159]

The provision of social and affordable housing is perceived as an urban planning strategy to propel social equality in LCC in China [62]. However, as Dou et al. [105] indicate, while there is a more significant potential to optimize energy-savings and consumptions in low carbon construction projects, the final cost will increase. Therefore, it is the role of the government to standardize low carbon construction requirements to facilitate the marginalized population. Yang et al. [180] propose that low-cost, affordable, and transitional rental housing should comprise 30% of all residential units in LCC neighborhoods. For instance, they illustrated that affordable housing was a standard allocation in the design principles of the Tianjin LCC, representing 10% of residential construction.

Additionally, the sustainable transport policy comprises many related but unique strategies that seek to increase access to public transportation, especially for neighborhoods dominated by low-income households [110]. Job-work balance and accessibility to critical facilities and services for the low-income group are major aspects of social equity in cities. A high degree of these planning components is associated with a higher proportion of non-motorized modes believed to have an impact on their motorized travel. This is critical, especially in sprawling cities such as Shanghai and Beijing where sprawling land use in transitional areas are characterized by the separation of employment and housing, thereby increasing daily commuting time for workers and impact travel modes [143]. Promoting social equity through the transportation sector in Beijing is paramount to the LC planning and investment strategy of the municipal government. With the improvement of social status and income, upper and middle-income groups can afford private vehicles. However, lower-income workers depend on public transportation [94]. As a result, the massive improvement of the public transportation system in the city has increased the accessibility for low-income workers and other disadvantaged groups [108].

At the national level, the government has placed greater emphasis on long-term urban GHG and energy intensity targets and identification of potential decarbonization pathways [174,183,184]. Meanwhile, LCC targets are inadequate on inter-generational justice concerns. Several scholars [8,31,123,127,165] have analyzed the targets of pilot cities in China. In the planning and implementation process of LCC, municipal governments establish relative and absolute quantitative targets for carbon intensity (per unit of GDP), the proportion of non-fossil fuel energy in the energy mix, and forest coverage rates [127]. These are used to define, analyze, and track progress toward a low carbon future [165]. In addition to these adopted targets, some LCC plans (Hangzhou, Shenzhen, Chongqing, Tianjin, Nanchang, and Xiamen) also include sub-sectoral targets for industries, buildings, transportation, and ecological sectors [8]. The literature reveals great variations in the temporal horizon and allocation of targets by cities. As it relates to the time horizon, both short-term (2015) and medium-term (2020) goals are common; however, long-term (post-2020) goals are rare and are only found in the city of Yan'an (to 2029) [165]. For example, Wang et al. [127] presented the temporal targets of 36 LCC pilot cities in China and found that 83% of the cities have released the targeted carbon discharge peak time, 97% of them have set up a target about the proportion of non-fossil fuels in primary energy consumption, and all have promised the forest coverage rate. Two-thirds of the LCCs have established a more stringent carbon reduction intensity than the national lower range of 40–45% by 2020 [31,127]. In general, the temporal time of the LCC targets (to 2020) extends beyond the present generation and covers its direct descendants. However, none of the targets extends to a long-term horizon (20 years and beyond). The current low-carbon urban construction also focuses on short-term economic goals [14,78,83], which makes it impossible to establish a long-term return on investment [185] and realization of substantial co-benefits.

The nature and challenge of decarbonization of the urban system cannot be undertaken incrementally but needs an unremitting long-term process of change [31,105,156]. The 5–10 years time horizon of the LCC targets might be beneficial for project implementation reasons, but is incapable of achieving the level of emission reduction that is required to stabilize global warming within the 2 °C required limit. Such a short-term perspective is far from innocuous in climate justice terms. This is because China is currently burdened with urban ecological, and environmental quality degradation, and inconsistency between energy supply and demand that creates bottlenecks in sustainable urban development [120,186,187]. Furthermore, Shin [37] and Lo [175] argued that there is a strategic tendency by local authorities to implement short-term LCC projects that fundamentally address specific and disaggregated tasks. This results in tangible, perceptible, and quantifiable outputs, over the development of long-term planning that requires more meticulous and qualitative analysis. Delineated using empirical evidence from Baoding, Lo [37] further suggests that long-term carbon emission reduction targets have limited the functional impact on professionals, given the short-term needs to meet the short-term goals. These factors jeopardize the establishment of long-term goals, which protect both the present and future generations. More importantly, it is essential that during policy formulations, short-term objectives are aligned with long-term development pathways and policies, to ensure consistency with specific targets. This is pertinent to avoid or reduce the intergenerational burden associated with the cost of carbon lock-in from the transformation infrastructures, transportation and mobility, utilization of non-renewable resources, environmental mitigation, and resource protection [146]. Therefore, a more realistic time horizon would be to the year 2050, as adequate planning, backcasting, and integration of key technologies can bring about a systematic change in seriously pursuing the 2 °C limit [188].

3.4. Scalability and Replicability

In general, LCC pilots involve testing and developing new technologies and approaches aimed at transforming the urban energy system. On the one hand, pilot projects serve as a "centre for excellence" for delivering current knowledge, simplification of models for customization, best practice, commercial viability, diffusion, innovative solutions, and experiences using experimentations, testing beds, living labs, and demonstration projects [181]. On the other hand, they provide a path through which barriers to implementation can be identified and remedied before wide-scale commercial roll-out.

At a national level, a dramatic shift towards scalable and replicable low carbon pilot projects and demonstration experiments have dominated the urban development landscape [7]. For example, Shin [37] identifies Baoding as a "litmus test" for successful pilot experimentation of LCC in China, given its comprehensive and long-term development strategies, which is usually copied by other cities. Since the launch of the low carbon pilot program in 2010, four groups of community typologies have included similar documents and policies to guide the transition of other cities in their low carbon efforts [8,11,37,187]. The developments include the National Low-carbon Ecological Demonstration City; the National Experimental Low-carbon City; the National Comprehensive Supporting Reform Trial Areas to Build a "Two-oriented Society"; and the International Cooperative Low-carbon Eco-community. These pilot experiments are identified as "seeds of change" used to co-create an array of state-of-the-art sustainable and viable "technological" solutions and innovative approaches that can be scaled-up and replicated to realize profound changes in the social, environmental, and economic nuclei of the cities [157]. Meanwhile, Yu [62] provides evidence from the Chinese Society of Urban Studies that 57% of cities in China have conveyed trepidations about the escalating cost of implementing LCC development in China. As a result, the study highlights that this precludes scalable, replicable, and practicable demonstration projects and solutions; therefore, further appropriate research is required to examine cost reduction.

Optimization of the economic and ecological potential in pilot cities is being enhanced through the promotion of joint urban development clusters. In the Guangdong Province, for example, three cities (Pingdi, Xinxu, and Qingxi) established a new regional zone, which "policymakers in Shenzhen were eager to replicate the developmental success of their core districts in its peripheral areas [24].". The Shenzhen international LCC demonstration project, located in the Longgang District, in a marginalized area of the city, emphasized the upscaling of the development project into three stages: The experimental stage (1 km^2), pilot stage (5 km^2), and large advance stage (entire 53.4 km^2) [189]. As they recognized, the project promoted the concept of "living laboratory" to develop and test ambitious, smart ICT, and infrastructures such as the mobile smart grid, smart transportation system, and the Internet of things (IoT). This is being achieved through knowledge and technology transfer to attract and attain financial and technical support from bilateral and multilateral partnerships to advance urban sustainability standards and practice. In another case, Qingdao constructed an LCE experimental zone and ecological park that plans, designs, and implements integrated low carbon energy solutions, energy-efficient buildings, lighting systems, and industry [79]. This demonstration zone development will provide an opportunity to boost whole-city low carbon commercial development and be a model for public–private partnership. Furthermore, centrally initiated projects in Baoding (e.g., the Golden Sun Demonstration) provide a template to scale up demonstration zones for distributed solar power [182]. Hangzhou became a national model for the implementation of LED lights, which was replicated in cities such as Nanjing [37]. Meanwhile, Tianjin has pioneered building an EE code, and design and technology models, which have provided standardized design guideline for other cities in China [33]. Moreover, cities such as Nanchang, Shenzhen, and Tianjin have established research centers, cooperation projects, and low carbon economic demonstration through collaborations. The success of the Guangzhou BRT system (environmental mitigation, economic return on investment, and physical design and operational management) is spurring BRT planning and design in Chinese cities such as Yichang and Lanzhou, as well as other Asian cities [165].

4. Conclusions and Future Research

This research provides a comprehensive overview of the LCC initiative in China in regards to its aim of promoting sustainability. The study explored an extensive and broad array of literature on LCC that has been peer-reviewed in scientific journals and conference proceedings, government documents, and international studies. Based on the four endogenous principles of sustainable development, a theoretical and conceptual framework was developed, and further validated through expert interviews and discussions. The key components of LCC were identified and discussed, and core shortcomings of the principles were identified. The results of this study help to establish the status of current knowledge, and highlight several avenues of future research, within the LCC domains.

The literature revealed an imbalance in the comprehensive approach to LCC pilots. There is a discernible bias towards the provision of technological innovations and strategies for environmental and economic domains of integration principle of sustainable development. Meanwhile, there is a nested structure to social and governance integration, implementation, equity, and scalability and replicability. Environment and economic strategies found and explored underpin a broader convergence on the reduction of GHG emission in Chinese cities. Although the social dimensions have received less focus, there is a rising number of literature that has explored both socio-demographic and socio-economic factors affecting lifestyle change and consumer behavior. This has heralded a new opportunity for enhancing and complementing technologically innovative-based strategies. Despite the changing tide worldwide towards participatory urban governance, the top-down governance structure is still dominant.

The study revealed that there is no coordinated, systemic approach that profoundly encapsulates the capacity to make and implement decisions and the extent to which these decisions recognize and respond to the interests of residents. This normative obstacle approach thwarts the urban regime to derive legitimacy from achieving collective sustainability goals. LCC implementation is currently at its infantile stage. However, several studies have identified a significant gap between the planning and implementation of LCC. This gap is attributed to a lack of strategic implementation framework, utopian visions, funding, and capacity building, and horizontal-vertical cooperation.

Regarding equity, the technocratic rationale planning approach dominates the planning and implementation process and excludes real public participation and engagement of crucial stakeholders such as residents, enterprises, and the civil society. There are some indicators of social equity planning such as access to public transport options to public transit stops, provision of non-motorized transport and infrastructures, barrier-free access to public and green spaces, increase access to job-housing balance, and increase local job creation, income disparities, and poverty reduction. However, planning for the most vulnerable population is absent from development strategies, and the literature has not identified the widescale goals of these factors. Moreover, LCC targets are meager on inter-generational justice concerns, as they mainly focus on carbon intensity reduction, the share of non-fossil fuel in the energy, and a carbon sink over a short to medium term. There is also a need for a "sharing and learning" city–city network system, which can enhance collaboration between cities, so that leading-edge technologies and strategies can be easily scaled-up and replicated.

Future research on LCC in China should focus on (1) devising appropriate regulatory and non-regulatory strategies to integrate socio-demographic and socio-economic factors to influence lifestyle and behavioral change; (2) the integration of stakeholder participation and engagement in the LCC planning process; (3) a triple-bottom-line collaboration between the government, enterprises, and universities/research institutes; (4) LCC inventory by sector and devising appropriate long-term targets to ensure deep decarbonization; (5) the assessment of LCC planning and barriers to implementation; (6) the interests of stakeholders in the planning and implementation of LCC; (7) research on co-benefits of LCC implementation; and (8) the scalability and replicability of LCC technological solutions; (9) smart cities solutions for low carbon city; and (10) linking green building and neighborhood certification with performance incentives and density bonus schemes.

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