Research on Optimization of Low-carbon Eco-city Indicator System in China from International Comparison Perspective

—Taking the China-Singapore Tianjin Eco-city and Bristol as examples

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Abstract: This paper, guided by the goals of "carbon peak" and "carbon neutrality," examines the Low-carbon Eco-city index systems of developed countries through international comparison. It identifies key points for constructing China's own index system under these goals and proposes a framework for optimizing China's Low-carbon Eco-city system. A comparison is made between the China-Singapore Tianjin Eco-city Version 2.0 and Bristol's urban development index, focusing on the index framework and specific data. The analysis highlights both similarities and differences. By drawing on Bristol's approach, it suggests increasing the share of renewable energy, developing clean energy, green building materials, renewable energy technologies, and smart technologies, while improving energy efficiency, reducing emissions, and enhancing carbon sink capacity. Based on these findings, relevant strategies for optimizing China's Low-carbon Eco-city index system are proposed.

1. Introduction

In September 2020, China set the "double carbon" goal of reaching carbon peak emissions by 2030 and achieving carbon neutrality by 2060, integrating these targets into the broader framework of ecological civilization [1]. The development of low-carbon eco-cities, focusing on carbon reduction, is a key strategy to meet this goal [2]. The eco-city index system not only reflects low-carbon eco-city theory but also provides a quantitative foundation for their development.

Many developed countries, particularly in Europe and the U.S., have implemented carbon emission reduction measures earlier than China, integrating them into their urban development indices to guide low-carbon eco-city construction. The UK, a pioneer in low-carbon eco-cities, updated its sustainability indicators in 2007 and released the White Paper "The UK Low Carbon Transition Plan" and "The UK Renewable Energy Strategy" in 2009, becoming the first country to include carbon emission management in its government budget framework. These approaches, along with strategic objectives for eco-city development, offer valuable insights for China's carbon control efforts. This paper compares the urban index systems of Bristol, UK, and Tianjin Eco-city to help optimize China's low-carbon eco-city index system in line with the "double carbon" goal.

2. Low Carbon Eco-City Index System Under the "Double Carbon" Goal

The concept of a "Low-carbon Eco-city" builds on the "Eco-city" model, focusing on low energy consumption, pollution, and emissions while promoting ecological balance. Its goal is to reduce greenhouse gas emissions and create sustainable urban environments, emphasizing the relationship between humans and nature [3]. The Low-carbon Eco-city index system serves as a tool for evaluating low-carbon development and guiding cities toward sustainability.

To achieve the "double carbon" goal, the system prioritizes optimizing energy, industry, and carbon sinks. This includes controlling carbon intensity, accelerating transformations in energy, industry, and transportation, and enhancing ecosystem carbon sink capacity, aiming to improve environmental quality and reduce pollution [4]. Proposed by Chinese scholar Qiu Baoxing, the system categorizes indicators into four areas: resources (water, energy, land), environment (air and water quality, waste, noise, parks, greenhouse gases), economy (industrial structure, income, employment), and society (housing, healthcare, education, social equity, transportation, urban safety)[5-6].

To meet the "double carbon" objectives, an efficient index system must focus on low-carbon and green

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development. This paper proposes a framework ("framework concept") with 36 indicators across four modules: resource conservation, low-carbon environment, social harmony, and green economy. It includes 19 key indicators related to energy supply, consumption, low-carbon environment, and carbon sequestration (highlighted in green, see Figure 1).

3. Case Comparison — China-Singapore Tianjin Eco-city and Bristol, UK as Examples

The China-Singapore Tianjin Eco-city is a strategic cooperation project jointly built by the governments of China and Singapore in 2008, and it is a typical demonstration of a Low-carbon Eco-city in China. Bristol, UK is one of the 10 Eco-towns that the UK government decided to build in 2007.

3.1. City Overview

The China-Singapore Tianjin Eco-city located in Tianjin Binhai New Area (Figure 2), it covers 31.23 km², with a planned population of 350,000. It features unique elements such as non-arable land use, a green transportation system, and innovative management models. Bristol, UK, is a historic coastal city with over 400,000 residents and a rich commercial history (Figure 3). It is now a major aerospace, high-tech, and financial hub in the UK [7]. Both cities share similarities in population size, geography, and strategic development goals (Table 1) but differ in national conditions and economic development, leading to variations in their respective index systems Despite these differences, both cities focus on reducing carbon emissions, with their index systems aiming to achieve carbon neutrality through carbon sequestration and carbon sinks across resources, environment, society, and economy.

3.2. Comparison of the Urban Development Indicator Framework Between the China-Singapore Tianjin Eco-city and Bristol, UK

In 2020, the China-Singapore Tianjin Eco-city introduced its 2.0 index system, aligning with national green and low-carbon policies. It focuses on four areas: ecological health, social harmony, green economy, and regional coordination, with ecological/environmental indicators at 53%, social at 37%, and economic at 10%. This structure emphasizes low-carbon development and a circular economy. In contrast, Bristol lacks a dedicated Eco-city index, instead using Regional Spatial Strategies and the Local Development Framework. The 2019 "A Plan for Bristol to 2050" identifies six priority themes aligned with the UN Sustainable Development Goals: 1) Connectivity, 2) Economy, 3) Environment, 4) Health and Wellbeing, 5) Families and Communities, and 6) Learning and Skills. This section compares the 2020 Tianjin Eco-city index with the 2019 Bristol local plan indicators within the "Double Carbon Goal Oriented Low Carbon Eco-city Indicator Framework" (Table 2).

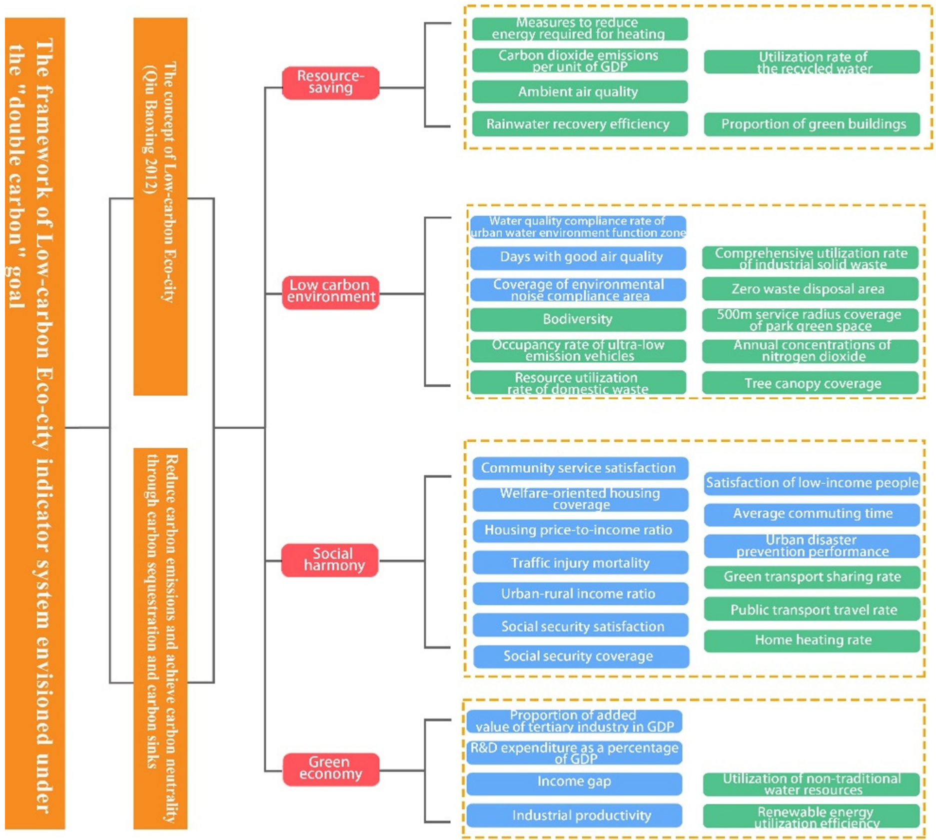

Fig. 1. The framework of Low-carbon Eco-city indicator system envisioned under the "double carbon" goal (self-drawn by the author)

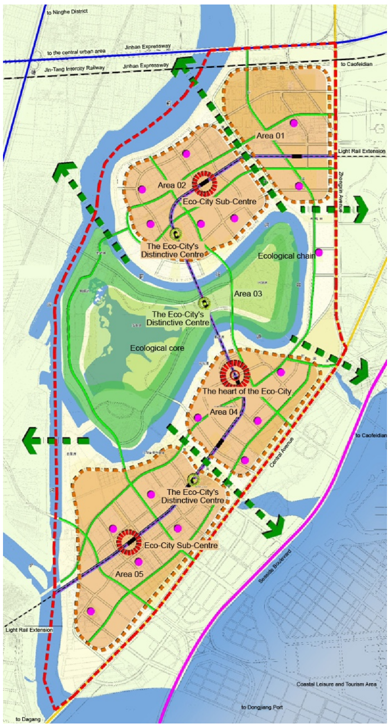

Fig. 2. Location Map of China-Singapore Tianjin Eco-city.

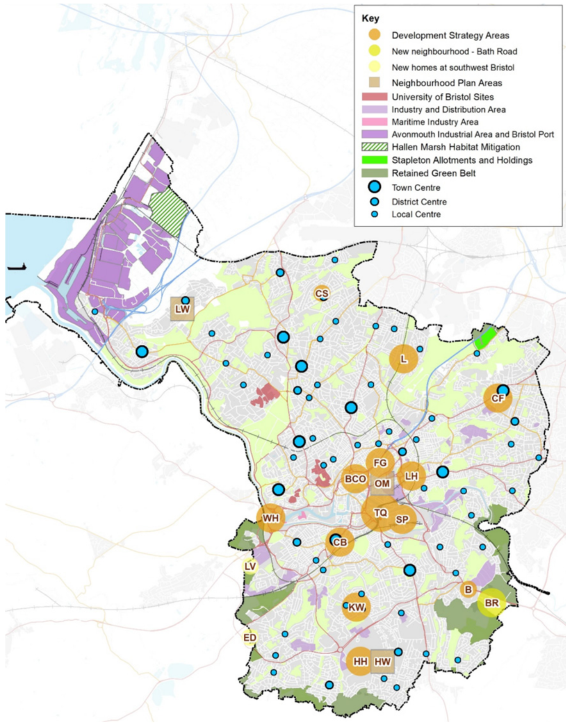

Fig. 3. Location Map of Bristol.

Table 1. Overview of China-Singapore Tianjin Eco-city and Bristol, UK (author's own drawing, data source: Council, B. A Plan for Bristol to 2050.)

	Population	Total area	Geographical location	Specify the starting point of the indicator system	Industry	Formulation agency	The administrative system of the designated unit
China-Singapore Tianjin Eco-city	The planned resident population is 350,000	About 31.23km^2	Located in Tianjin Binhai New Area	Committed to building a Low-carbon Eco-city that is high-end, advanced, reproducible, and scalable, and benchmarked against international leading Eco-city development goals	Ecological scientific and technological industry, information industry, environmental protection industry, film and television industry, animation industry, etc.	Ministry of Housing and Urban-Rural Development of the People's Republic of China	The administrative department in charge of construction under the State Council
Bristol	The planned resident population exceeds 400000	About 110km^2	Located in the southwest of England, it is an important commercial port	Rooted in a master plan, committed to building fair, healthy and sustainable communities	Agriculture, textile industry, engineering industry, aviation industry, etc.	Bristol City Council	British local government

3.2.1 "Double Carbon" Analysis in the Construction of Indicator Framework

Of the 19 key indicators from the "Framework Vision," 11 (52.6%) are adopted in the China-Singapore Tianjin Eco-city and 17 (89.5%) in Bristol, indicating that Bristol's indicator framework is more advanced. According to "A Plan for Bristol to 2050," carbon reduction should prioritize energy efficiency, carbon intensity reduction, increasing low-carbon energy, decreasing high-carbon energy, strengthening natural carbon sinks, and utilizing CCUS.

3.2.2 The Dynamics of Indicator Framework Construction

In the 2019 "A Plan for Bristol to 2050," the city divides its urban development vision into three stages, each covering a 10-year period. The plan introduces multiple specific indicators that are progressively advanced in the index system for each stage. This demonstrates that the Low-carbon Eco-city approach in the UK takes into account the dynamic nature of index updates, a practice that is valuable for reference.

3.2.3 Resilience of Goal Tier Indicators in the Indicators Framework

The indicator layers of the two systems differ significantly. Bristol's indicators do not assess implementation through specific rates, making the UK's Low-carbon Eco-city planning more flexible (see Table 3). These layers describe indicators without defining specific ranges, indicating that city planners set limits in other specialized urban planning. This contrasts with China's top-down model, shaped by national conditions and institutional frameworks.

3.3. Comparison of Urban Development Indicators Between China-Singapore Tianjin Eco-city and Bristol, UK

This study compares the 19 key indicators in the "Framework Concept" with the indicator systems of Tianjin China-Singapore Eco-city 2.0 and Bristol, analyzing resources, environment, economy, and society (see Table 3). It highlights data representation and numerical differences across categories. While there are minor differences in the indicator frameworks, units, and goals, these can be reconciled through normative descriptions in academic references.

Table 2. Comparison of urban development indicator framework between China-Singapore Tianjin Eco-city and Bristol, UK (author's own drawing, data source: Refs. [2, 8-9]).

Assumption of low-carbon Eco-city indicator framework		**Sino-Singapore Tianjin Eco-city**			**Bristol**	
Topic	Index	Goal layer	Standard layer	Index layer	Topic	Index
Resource-saving	Carbon dioxide emissions per unit of GDP	Healthy ecological environment	Excellent natural environments	Ambient air quality in the area	Environment	Water condition
				Environmental quality of surface water in the area		Guarantee water quality and sewage treatment
	Measures to reduce energy required for heating			Noise up-to-standard rate in functional area		Number of wild animals
				Wetland protection rate		Annual concentrations of nitrogen dioxide
	Proportion of green buildings			Ecological revetment retention rate		Carbon dioxide emissions
	Ambient Air Quality		Liveable urban environment	Native vegetation index		Tree canopy coverage
	Intensity of urban heat island effect			5 minutes' walk to the park Green residential area ratio		Ten minutes' walk to high-quality green space
Low-carbon environment	Rainwater recovery efficiency				Homes and Communities	Community attachment
	Days with good air quality			Intensity of urban heat island effect		Source of household heating rate
	Annual concentrations of nitrogen dioxide	Harmonious development of society	Healthy lifestyle	Daily per capita domestic water consumption		Supply of social security housing
	Occupancy rate of ultra-low emission vehicles			Daily waste production per capita		Bureau of Primary Health Care
	Water quality compliance rate of urban water environment function zone			Proportion of green buildings		Sources of fruit and vegetable supply
				Proportion of green travel		Homelessness rate
	Resource utilization rate of domestic waste			Community vitality		Residential density in city centers
	Comprehensive utilization rate of industrial solid waste			Residents' life satisfaction		Garbage utilization
				Health literacy level of residents		Healthcare and social services
	Coverage of environmental noise compliance area		Improvement of infrastructure	Ratio up to the standard of water quality		Community zero waste treatment measures
	Tree canopy coverage			volume capture ratio of annual rainfall		Travel mode
	500m service radius coverage of park green space			Proportion of residential areas with free cultural and sports facilities within a 500-meter walk	Learning and Skills	Community cultural diversity and history courses
						Urban counseling plan and reverse counseling plan for the elderly
	Biodiversity			Coverage of barrier-free facilities in public spaces		Adult education and childcare facilities
Social harmony	Zero waste disposal area					Affordability of child care
	Welfare-oriented housing coverage		Improvement of			Free high-quality preschool education

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	Housing price-to-income ratio		management mechanism	Proportion of affordable housing to total housing in the district		Gap in early development of poor children
	Traffic injury mortality			Recovery utilization ratio of rubbish	Health and Wellbeing	Life expectancy gap between rich and poor areas
	Urban-rural income ratio			Reuse ratio of treated sewage		Incidence of infectious diseases
	Green transport sharing rate			Social security coverage		Household debt
	Social security coverage					Average waiting time for social housing
	Satisfaction of low-income people		Intelligent and efficient operation and management	Urban intelligent management	Connectivity	Traffic fatality and congestion rate
	Average commuting time	Green and low-carbon economy	Efficient use of resources	Carbon emission intensity per unit of GDP		Proportion of passengers on public transport
	Urban disaster prevention performance					Traffic fatality and congestion rate
	Social security satisfaction		Technology-driven innovation	Proportion of renewable energy		Arrive at the transportation hub within five minutes from home
	Public transport travel rate			Utilization of non-traditional water resources		Electric vehicle charging network coverage
	Community service satisfaction					Zero carbon emission of vehicles
	Home heating rate			Enterprise innovation activity		Popularity of public transport vehicles choosing electric vehicles
Green economy	Proportion of added value of tertiary industry in GDP			Research and development manpower input intensity		Proportion of ultra-low emission vehicles (ULEV)
						Develop public transportation and ensure lowcarbon travel
	Proportion of research and experimental development expenditure in GDP		City-industry integration development	Jobs-housing balance index	Economy	Proportion of energy from clean energy
	Income gap	Regional coordinated development	Natural ecological coordination			Number of start-ups
			Regional policy connection			Equal employment and educational opportunity
	Industrial productivity		Social integration and development			Integration between neighbourhoods and employers
	Utilization of non-traditional water resources		Industry coordination and optimization			Rainwater recovery efficiency
	Renewable energy utilization efficiency		Multicultural symbiosis			
			Urban landscape shaping			Use of sustainable smart energy

Table 3. Comparison of urban development indicators between China-Singapore Tianjin Eco-city and Bristol, UK (author's own drawing, data source: Refs. [2, 8-9]).

19 key indicators		**Sino-Singapore Tianjin Eco-city**			**Bristol**		
Topic	Index	Goal layer	Index	Indicator description	Topic	Index	Indicator description
Resource -saving	Carbon dioxide emissions per unit of GDP	Healthy ecological environment	Ambient air quality in the area	By 2028, the number of days better than or equal to the secondary standard is ≥ 310 days/year (equivalent to 85% of the whole year) By 2023, the air quality comprehensive index improvement rate is ≥ 20%. By 2023, the air quality comprehensive index	Connectivity	Electric vehicle charging network coverage	Build a comprehensive EV charging network by 2028
	Measures to reduce energy required for heating					Zero carbon emission of vehicles	All transport to be zero carbon by 2040

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				improvement rate is ≥ 20%.			
	Proportion of green buildings		Intensity of urban heat island effect	No more than 2.5°C by 2035		Popularity of public transport vehicles choosing electric vehicles	95% of public service vehicles within the city center are completed by freight-integrated electric vehicles, with integration centers located on all critical transit
	Ambient air quality		Number of native plants	Not less than 0.7 by 2023		Proportion of ultra-low emission vehicles (ULEV)	20% of the taxi fleet and private taxi fleet are ULEVs by 2024 75% of the taxi fleet and private taxi fleet are ULEVs by 2032 25% of cars are ULEV by 2034; 75% of the public sector fleet is ULEV by 2035 50% of cars are ULEV by 2040 100% of cars are ULEV by 2048
	Intensity of urban heat island effect					Develop public transportation and ensure low-carbon travel	The number of people using public transport using active modes of transport (walking, cycling) has increased year by year since 2018, and all public transport is carbon-neutral by 2050
	Rainwater recovery efficiency		5 minutes' walk to the park Green residential area ratio	100% by 2025	Economy	Proportion of energy from clean energy	95% of all energy (electricity, heat, transport) consumed by cities from clean sources by 2042
Low-carbon environment	Annual concentrations of nitrogen dioxide					Rainwater recovery efficiency	Rainwater is recycled in properties across the city by 2039
	Occupancy rate of ultra-low emission vehicles		Proportion of green buildings	100% by 2023		Use of sustainable smart energy	By 2023, more than 50% of households will use smart energy technology; by 2030, the main development will be net carbon negative, and it will be smart energy
	Resource utilization rate of domestic waste	Harmonious development of society	Proportion of green travel	Not less than 65% by 2023 No less than 95% by 2035	Homes and Communities	Community zero waste treatment measures	65% of household waste sent back for reuse and composting by 2029 80% of household waste sent back for reuse and composting by 2039 90% of household waste sent back for reuse and composting by 2048 Achieving zero residual household waste by 2050
	Comprehensive utilization rate of industrial solid waste					Source of household heating rate	By 2032, 75% of households will use high-standard (C+) insulation materials, reducing the need for home heating and reducing the energy required for home heating Home heating from zero-carbon sources by 2045 75% of non-residential buildings with high standard (C+) insulation by 2047, reducing the need to heat homes
	Tree canopy coverage		Recovery utilization ratio of rubbish	No less than 65% by 2028 No less than 70% by 2035			
	500m service radius coverage of park green space					Waste utilization rate	Reuse and compost 50% of all waste collected by cities by 2029
	Biodiversity		Daily waste production per capita	No greater than 0.8 by 2023		Travel mode	In 2043, 60% of journeys will be by active modes, including walking and cycling

	Zero waste disposal area	Green economic development	Carbon emission intensity per unit of GDP	No more than 120 tons of CO_2/million U.S. dollars by 2028 No more than 100 tons of CO_2/million U.S. dollars by 2035	Environment	Carbon dioxide emissions	Reduced to less than 1,500 tons by 2023 Reduced to less than 1,000 tons by 2029 Reduced to less than 500 tons by 2039 Reduced to less than 100 tons by 2049
Social harmony	Home heating rate					Number of wild animals	Wildlife significantly higher by 2038 than in 2018 Wildlife populations to double 2018 levels by 2044
	Green transport sharing rate		Proportion of renewable energy	No less than 20% by 2023 No less than 25% by 2028		Tree canopy coverage	A quarter more than in 2018 by 2035 Double the 2018 level by 2046
	Public transport travel rate					10 minutes' walk to high-quality green space	By 2037 everyone will have access to quality green space within a 10-minute walk from their home
Green economy	Utilization of non-traditional water resources		Utilization of non-traditional water resources	No less than 55% by 2028 No less than 60% by 2035		Annual concentrations of nitrogen dioxide	All below 40ug by 2023 All below 30ug by 2034 All below 15ug by 2046 All below 10ug by 2050
	Renewable energy utilization efficiency						

3.3.1 Resource, Environmental, Economic, and Social Aspects

The "Resources" and "Environment" modules of the "Framework Scenario" evaluate key sustainability indicators for both cities. Bristol aligns with 83.3% of the "double carbon" goal, while Tianjin reaches 66.7%. In the "Environment" module, eight indicators are used, with three shared between the cities. Bristol aligns with 100% of these, while Tianjin reaches 37.5%. Notable indicators include:

①Energy Carbon Emissions: The UK prioritizes reducing energy-related emissions, with Bristol aiming for zero emissions by 2050, having already achieved zero emissions for all development projects by 2019.

②Ambient Air Quality: Bristol maintains stricter air quality standards than Tianjin, showing continuous improvements supported by the UK's integrated pollution and greenhouse gas management system [10].

③Green Building Proportion: Tianjin Eco-city targets 100% green building compliance for new constructions, while the UK focuses on retrofitting existing buildings using eco-friendly designs and materials to reduce CO2 and improve building lifecycle performance.

④Domestic Waste Resource Utilization: Tianjin aims for 65% recycling by 2028 and 70% by 2035. Bristol follows a phased, stricter approach to waste separation, aligning with the "double carbon" goal.

⑤Canopy Coverage: Bristol aims to enhance green transport access in parks by introducing new plant species, while Tianjin's plant index is more specific but lacks the cultural-environmental integration of Bristol's approach.

⑥500-meter Service Radius of Park Green Space: Both cities use this indicator, with Bristol focusing on per capita green space and accessibility[11], while Tianjin emphasizes it more due to economic differences, as UK cities typically offer more green space per capita than Chinese cities[12].

For the economic and social aspects, both cities focus on green transportation and renewable energy:

①Green Transportation: Both cities promote green transportation, but Bristol addresses unsustainable commuting by functional zoning and shifting employment patterns, reducing carbon emissions per passenger unit [13].

②Renewable Energy: Bristol aims to increase its renewable energy share (geothermal, wind, solar) for sustainable heat and electricity, with a goal of zero emissions by 2050. Tianjin targets at least 28%, although direct comparison is difficult due to differences in development stages.

3.3.2 Description of Variability Indicators

These 19 key indicators align with the "double carbon" goal, covering energy supply, consumption, low-carbon environment, and anthropogenic carbon sequestration. However, as shown in Table 3, Bristol's indicator system includes several more specific indicators such as "carbon neutrality," "short-distance carbon supply chain reduction by community retailer Yupixi," and "zero waste community." These indicators have become increasingly emphasized through Bristol's planning stages, underscoring that Bristol's carbon reduction, sequestration, intensity control, and urban management requirements are more stringent than those in China.

4. Optimizing China's Low-carbon Eco-city Index: An International Comparison

Taking Bristol as an example, its Low-carbon Eco-city planning focuses on enhancing carbon sink capacity, with the following key features: ①The primary goal is to reduce carbon emissions, tracked through quantitative indicators [14]. ②Strategies include promoting renewable energy, improving energy efficiency, and controlling energy demand. ③Key sectors for planning are buildings and transportation [15]. ④The approach integrates both strategic objectives and practical measures. ⑤The planning highlights the roles of technology, policy, and public governance [14]. Based on these points, strategies for optimizing China's Low-carbon Eco-city index system are proposed.

4.1. Resources and Environmental Aspects

① Coal is the largest source of carbon emissions in China. Reducing emissions from coal power and increasing renewable energy share (e.g., geothermal, wind, solar, ocean, nuclear) are key challenges for achieving the "double carbon" goal. Expanding clean energy indicators is essential for guiding technological and industrial progress [16].

② Green building materials, renewable energy, and smart applications reduce energy waste, offset carbon emissions [17], and promote energy-efficient construction. HVAC technology advancements improve efficiency and eco-friendliness. Renewable energy can meet low demand, reduce emissions, and enhance efficiency. Digitalization optimizes urban energy management.

③ Strict monitoring of pollutants and greenhouse gases, supported by a synergistic management system, reduces pollution costs and eliminates carbon lock-in effects, aiding the "double carbon" goal.

④ Carbon reduction measures include increasing green building compliance, promoting innovative designs, reducing CO_2 emissions, and improving building lifecycle performance.

4.2. Social and Economic Aspects

① Inspired by Bristol's bio-economy model, increasing bio-energy fuel indicators will help shift the energy structure, foster innovation, replace fossil fuels, improve efficiency, and reduce emissions.

② Optimizing the economic and industrial structure is key for energy conservation and efficiency improvement. This will help China decouple economic growth from rising energy consumption [18-19].

③ Focus on green transportation indicators to reduce carbon intensity per passenger. A continuous, accessible slow travel system will guide low-carbon travel, reduce fossil fuel reliance, and lower transportation emissions.

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