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From Policy to Implementation—An Analytic Network Process (ANP)-Based Assessment Tool for Low Carbon Urban and Neighborhood Planning

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Abstract: To achieve the goals of carbon peaking, a national policy instrument for carbon peaking in the building and construction sector has been launched by the Chinese MOHURD (30 June 2022). We have developed an actionable framework for implementing these policy objectives. The framework was designed by classifying and prioritizing selected strategic government recommendations in the form of an interactive indicator system and tool for evaluating the quality of low-carbon urban and neighborhood planning actions based on the decarbonation principles of carbon emission reduction and carbon capture. The analytic network process (ANP) was applied for processing the interactions and prioritizing the indicators (23 in total for the two principles applied). A scorecard was designed for assessing low-carbon urban and neighborhood planning strategies and technologies. The practical implementation of the tool was then tested with two real planning cases, one from a fourth-tier Chinese city and another from a high-density city. The applicability of the tool is further discussed by comparing it with well-developed international assessment tools in other contexts. This article contributes to the literature by first initiating research on the use of this evaluative tool for low-carbon planning and secondly by demonstrating how researchers can convert policies into practical implementations.

Keywords: Chinese carbon policy; carbon peaking; urban and neighborhood planning; evaluative tool

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1. Introduction

1.1. Background

On 9 August 2021, the United Nations Intergovernmental Panel on Climate Change (IPCC) released the Working Group I Report on Climate Change. This report on climate change throughout history drew a brutal picture for the future [1]. Actions must be taken now to limit global warming to 1.5 °C. Achieving this goal would require global greenhouse gas emissions to peak by 2025 at the latest, and to decrease by a quarter by 2030 [2–4]. As the world's largest carbon dioxide emitter [5], China's emissions reduction rate plays an essential role in limiting climate change to 1.5 °C. According to IEA statistics, buildings and construction account for 37% of global energy-related carbon dioxide emissions [6]. With the rapid advancement of Chinese urbanization and the adjustment of its industrial structure, carbon emissions in the construction sector and their proportion of the total carbon emissions of the whole society are destined to further increase [7]. Aggressive countermeasures are needed.

To deal with increasingly severe climate change, China has continued to strengthen its energy conservation and emission reduction efforts by formulating a series of goals and measures. As can be seen in Figure 1, on 22 September 2020, China made a commitment to the world that the country would strive to reach a peak in carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060 (referred to as a "double carbon" national goal). At the Climate Ambition Summit in December 2020, China announced further commitments for 2030: it will reduce carbon dioxide emissions per unit of GDP by over 65 percent from the 2005 level, increase the non-fossil share in primary energy consumption by 25 percent, increase the forest stock volume by 6 billion cubic meters compared with 2005, and bring its total installed capacity of wind and solar power to over 1200 GW [8]. On 22 April 2021, China pointed out at the Leaders Climate Summit that it was obliged to undertake arduous efforts. For instance, China will strictly control coal-fired power generation projects by limiting the increase in coal consumption over the 14th Five-Year Plan (2021–2025) period and phasing it down during the 15th FYP period [9]. On October 2021, China released *The Instructions for Carbon Dioxide Peaking And Carbon Neutrality* [10] and the *Action Plan for Carbon Dioxide Peaking before 2030* [11]. These have led to the implementation of new norms in national development, including new directives in the energy sector, industry, construction, and transportation, as well as other key industries such as coal, electricity, steel, and cement. A "1 + N" policy framework will be formed with a timetable, roadmap, and action plans to achieve carbon dioxide peaking before 2030 and carbon neutrality before 2060 [12]. The "1" in this policy framework refers to those top-level governmental measures, and "N" refers to more than 30 national and local policies and measures introduced related to carbon peaking and carbon neutrality in specific fields and industries.

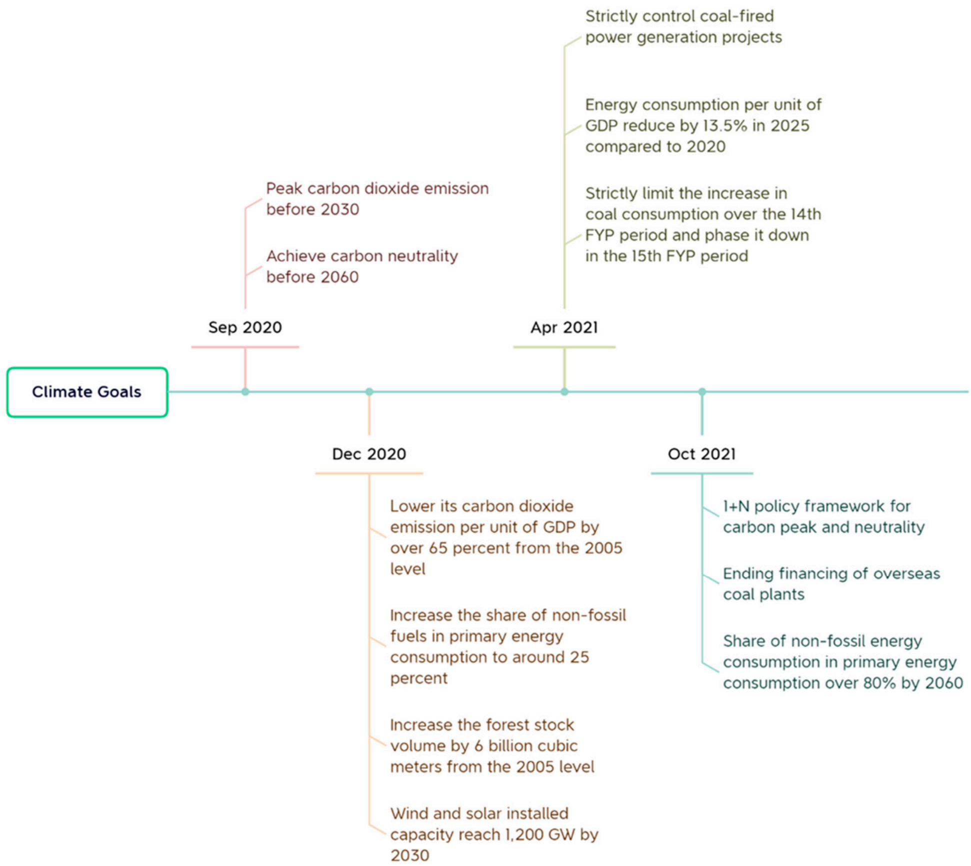

Figure 1. Major climate goals for the Chinese construction sector. Source: authors, based on [8,10,11].

1.2. A Glimpse of the World's Top Carbon Emitters: Sino–U.S. Carbon-Emission Reduction Policy Instruments for Construction Sector

As the world's top two emitters of carbon dioxide [13,14], both China and the United States have adopted action plans to achieve peak carbon neutrality. However, the top-down policies and their implementation for Construction Sector in China and the United States differ greatly.

Table 1 presents a summary of carbon-emission reduction policy instruments of China and the United States. The *Action Plan for Carbon Dioxide Peaking before 2030* published by the Chinese State Council explains the four Chinese pathways aiming at Construction Sector—first, promoting the green and low-carbon transformation of urban and rural construction; second, achieving improvements in building energy efficiency; third, accelerating the optimization of the energy consumption structures of buildings; and fourth, promoting low-carbon development at the rural level. Based on these pathways, the Ministry of Housing and Urban–Rural Development (MOHURD) has formulated an implementation plan, "*Chinese Carbon Peaking Instruments for the Construction Sector*, 30 June 2022" [15]. The details of this policy document are summarized in Section 2.3.

Table 1. Summary of the Chinese Action Plan for Carbon Dioxide Peaking before 2030 and the Pathways to net-zero emissions by 2050 in the United States.

Policy Name	Action Plan for Carbon Dioxide Peaking before 2030	Pathways to Net-Zero Emissions by 2050
Country	China (Top–Down Policy, Aiming at the Construction and Operation Levels)	The United States (Top–Down Policy, Aiming at the Consumer Level)
Pathways	Promoting the construction of urban and rural green low-carbon transformation	Decarbonize electricity
	Enhance the level of energy efficiency in buildings	Electrify end-uses and switch to other clean fuels
	Accelerate the optimization of the energy consumption structure of buildings	Cut energy waste
	Promote rural development and low-carbon transition to energy use	Reduce methane and other non-CO_2 emissions
	–	Scale up CO_2 removal

On the other hand, the United States has made a commitment to carbon neutrality by 2050. "*The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*" was published by the U.S. Department of State and the US Executive Office of the President, DC, in November 2021, introducing pathways targeting net-zero emissions by 2050 [16]. It emphasizes that the priority for 2020–2030 is to improve energy efficiency and increase the share of sales of clean and efficient appliances, including heat pumps for air conditioning, heat-pump water heaters, electric and induction stoves, and electric clothes dryers. As for achieving 100% clean generation by 2035, the government plans to eliminate upstream emissions from electricity and promotes the carbon-free and efficient electrification of appliances and equipment in all buildings. In addition, the government has suggested five potential paths to net zero emissions by no later than 2050 (Table 1).

As can be seen from the above comparison, the two nations have adopted different policies and directions. The Chinese carbon peaking policy focuses on the decarbonization of the process of building design and construction because China, as a developing country, has large demands in terms of buildings and construction. In addition, due to differences in economics and the infrastructural developments of various urban and rural regions, the corresponding carbon peaking strategies adopted by these vastly different urban and rural regions also differ. In contrast, the U.S. strategy focuses on the operation stage of buildings. This is because the U.S. is a developed country with a relatively low demand for energy for the construction of buildings. As a result, its policy focuses on renewable energy applications and improvements in the energy efficiency of public and residential buildings.

In fact, despite the instruments and directions for carbon emission reduction in these two countries differing greatly, carbon capture and storage (CCS) is emphasized as the most powerful path to long-term emissions reductions, with a focus on improving efficiency, economic viability, and safety [17]. Hence, it is adapted as one of the two principles of decarbonization in this study, and the other principle is carbon emission reduction.

1.3. Low-Carbon Cities

In China, more than 80 percent of carbon emissions come from cities [7,18–20]. Urban planning plays a key role in implementing low-carbon cities since the optimal urban form enhances natural ventilation, green spaces, carbon sinks, etc., all of which can help reduce the urban heat island effect, and eventually reduce greenhouse gas emissions [21]. In fact, in the past years, national and local governments have attempted various policies to reduce urban carbon emissions [22–24]. However, there are as many as 663 cities in China, including four independent municipalities that are directly under the jurisdiction of the Central Government, 293 prefecture-level cities, and 366 county-level cities, which can be ranked from the first tier to the fifth tier, and these different tiers of cities exhibit different economic, social, and physical planning characteristics. As a result, these vast differences create difficulties in the implementation of national initiatives.

1.4. Research Objectives

Based on the above reviews, in this study, we focused on investigating how to convert these policies to urban and neighborhood planning strategies and assessment tools for practical use. The objectives were (1) to develop a low-carbon urban and neighborhood planning indicator system with priorities (i.e., ranking by weighting) and credits (i.e., issued each indicator a score based on the weighting result) based on the MOHURD policy document "*Chinese Carbon Peaking Instruments for the Construction Sector*" [15] for practical applications; and (2) to evaluate the practical implementation of the low-carbon assessment tool for urban planning and neighborhood application by interacting with real-life projects.

In Section 2 we present the step-by-step methodology used by the researchers to arrive at a holistic framework for evaluation. Section 3 relates to the Analytic Network Process (ANP) at work, analyzing the interactions of selected provisions for decarbonization. In Section 4, the practical implementation of the tool is then demonstrated via two real planning case studies. The applicability of the tool is further discussed by comparing it with the well-developed international assessment tools in other contexts.

2. Methodology

2.1. Decision-Making Method—Analytic Network Process (ANP)

The analytic network process (ANP) is a well-developed decision-making tool, proposed by Thomas L. Saaty, which adapts to a non-independent hierarchical structure [25,26]. The analytic network process illustrates the relationships between each indicator in the system and reveals how the indicators in the network layer influence and dominate each other [27]. In contrast with a simple hierarchical structure, ANP, which describes the connections between the indicators/elements accurately [28], was chosen for this research.

ANP subdivides an indicator system into two layers: the upper layer is a control layer, whereas the lower layer is a network layer. Generally, the control layer contains goals and principles, and the network layer includes clusters and the elements/indicators/factors under the clusters. The control layer dominates the clusters and indicators in the network layer. The clusters and the internal indicators influence each other, which forms the network structure (Figure 2). It is worth noting that the essential components for an ANP structure are a "goal", two or more "clusters", and the "indicators/ elements" of the clusters.

The ANP calculation process is complicated due to the fact that it is designed for hypermatrix operation. Hence, Super Decision Software Version 3.2—a decision support software that implements AHP and ANP—was recruited in this study to assist our calculations, generate the matrix, and obtain the priorities of the indicators.

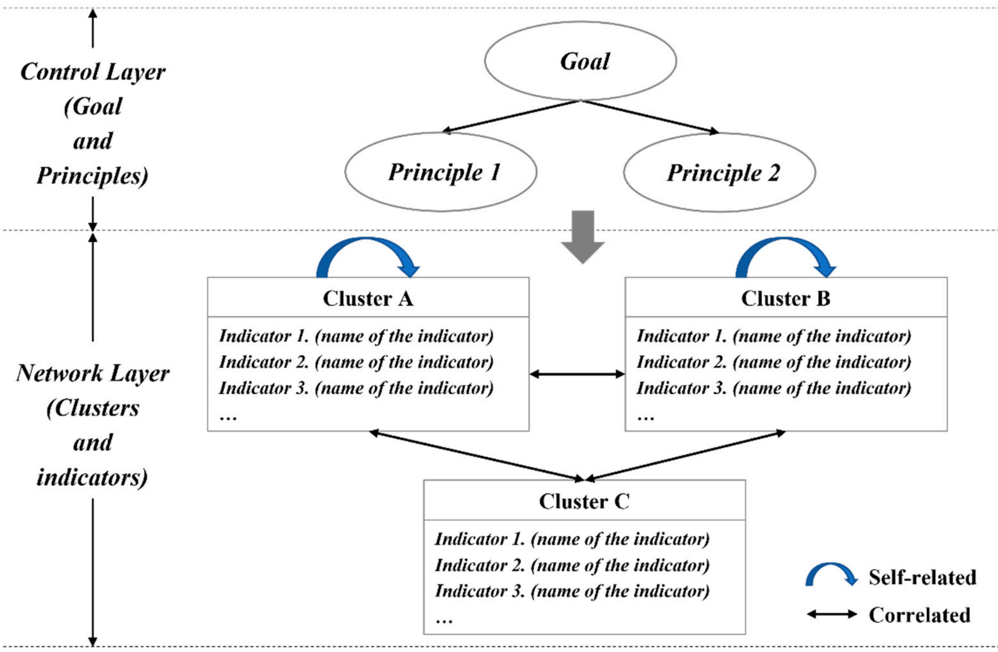

Figure 2. A typical ANP framework and process (illustrated by the authors) [25].

2.2. The Flow of Research

Figure 3 presents a flowchart of the methodology used in this study. First, the policy document *China Carbon Peaking Instruments for the Construction Sector by MOHURD* was selected as the source for this study (Table 2). Secondly, a screening process (the blue color box in Figure 3) was conducted to select those provisions that were most relevant to low-carbon urban and neighborhood planning strategies and technologies. Thirdly, the inclusive provisions (i.e., Provision #4, Provision #8, Provision #5) form a 23-item indicator system for low-carbon urban and neighborhood planning, with each of the three provisions as a sub-set of the indicators (Table 3). The third step (the orange color box in Figure 3) is developing an analytic network process (ANP) network—a well-developed decision-making tool—based on the method in Section 2.1. After defining the goal as "decarbonization" and the two principles/clusters of "carbon-emission reduction" and "carbon capture" based on the literature review in Section 1.2, all 23 indicators in Table 3 were re-grouped according to these two principles. The next step involved scoring based on pairwise comparisons of the network system and the application of Super Decision Version 3.2 for weighting calculations. Finally, a scoring system/a credit system with a total of 500 scores/credits based on the above weighting process was developed as an assessment tool, named *An Assessment tool for Low Carbon Urban and Neighborhood Planning*—with which the credits for each of the indicators can be calculated.

Moreover, a case study is a validated method and is widely used to testify to the practical implementation of an assessment tool [29]. In this study, the source document is a national policy instrument, and its scope of application needs to cover cities with different levels of economic development (the first to fifth-tier cities in China mentioned in Section 1.3). As a result, after developing the assessment tool, two cities with distinct differences in economic and urban development are selected to represent two urban patterns in China for the case study. The fourth-tier city Wuzhou is selected as a case to represent the small and medium-sized cities in China—which are characterized by relatively low-level economic development and have sufficient undeveloped areas. On the other hand, another case is from Hong Kong SAR. This is because Hong Kong is a representative of Chinese high-density and first-tier cities, which are characterized by high levels of economic development, and great economic strength and have limited undeveloped lands in cities. The final step is to further discuss the applicability of the tool by comparing it with well-developed international assessment tools in other contexts.

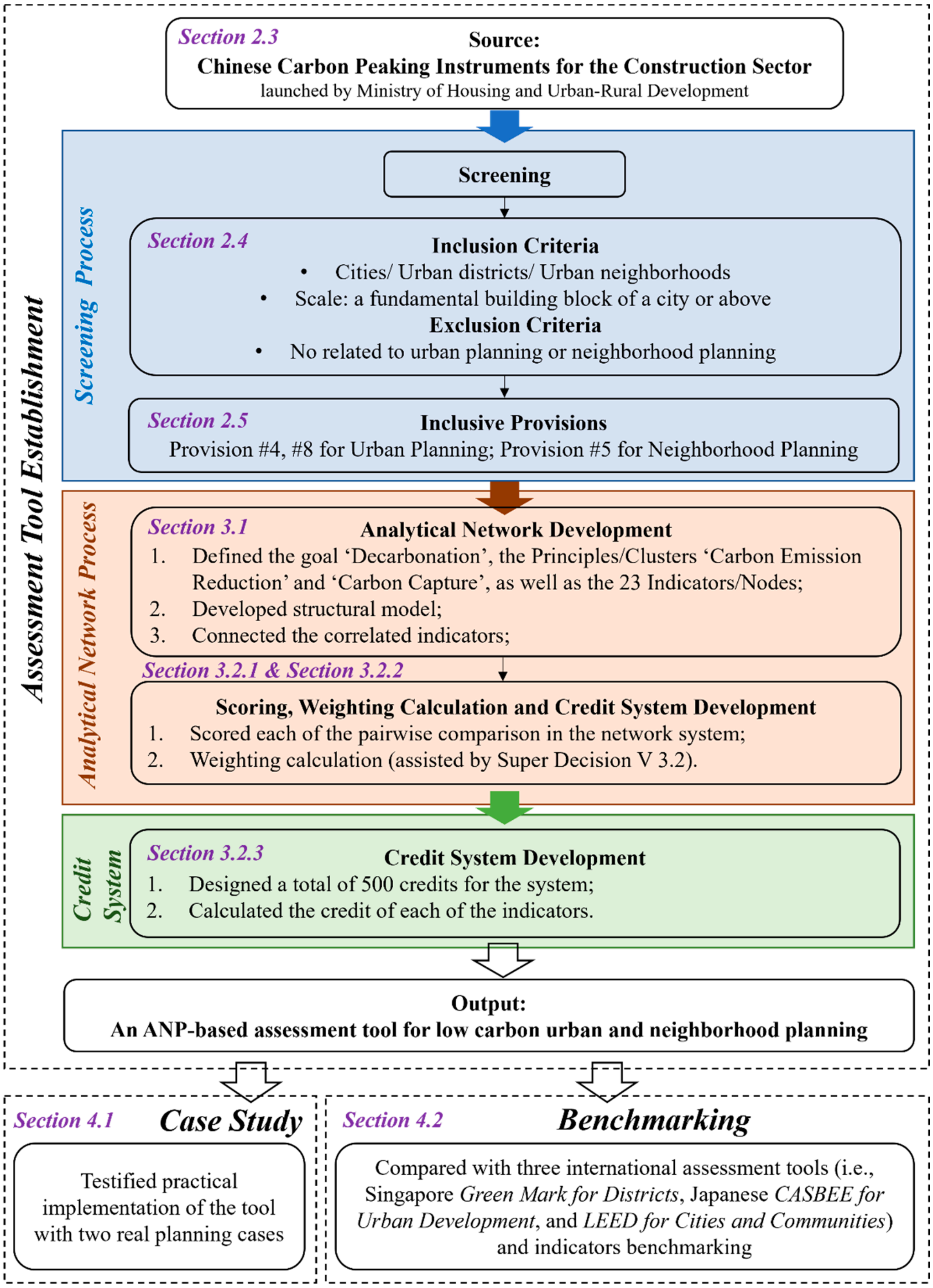

Figure 3. Flowchart for this study.

Table 2. Re-classification of the policy instruments for carbon peaking in the building and construction sector.

Scope	Applied Geography	No.	Provisions	Actors
A. Planning	Urban Planning	#4	Urban Structure Improvement	Planner
		#8	Urban Infrastructure Improvement	Planner
	Rural Planning	#11	Green and Low-Carbon Rural Areas	Planner
		#12	Natural and Compact Rural Patterns	Planner
B. Neighborhood Planning	Urban Neighborhoods	#5	Green and Low-Carbon Neighborhoods	Planner, Architect
C. Building Design	Urban Non-residential	#6	Green and Low-Carbon Buildings	Architect
	Urban: Residential	#7	Green and Low-Carbon Residences	Architect
	Rural: Residential	#13	Green and Low-Carbon Farmhouses Construction	Architect
D. Construction	N.A.	#10	Green and Low-Carbon Construction	Contractor
E. Operation and Management	N.A.	#16	Laws and Regulations and Standard Measurement System Improvement	Policymaker/ regulator
		#17	Green and Low-Carbon Transformation Development Model	Government/ Engineer/ Consultant
		#14	Low-Carbon Treatment of Domestic Waste and Sewage	Government/ Engineer
F. Renewable Energy	Urban	#9	Energy Utilization Structure of Urban Construction Optimization	Government/ Engineer/ Consultant
	Rural	#15	Renewable Energy Application Improvement	
G. Green Finance	N.A.	#19	Financial and Fiscal Support Policies Improvement	Policymaker/ regulator/ financial sector
H. Education	N.A.	#18	Integrated Mechanism of Production, Education, and Research Establishment	Government/ Industry/ University
		#22	Training and Publicity	Government

Table 3. Included provisions and indicators (the specifications as interpreted by the authors are shown in Appendix A).

Provisions	Indicators
Urban Structure Improvement (USI) (9 indicators) Provision #4	USI 1. Layout Planning USI 2. Population Density USI 3. Green Corridors USI 4. Ecological System Restoration USI 5. Height of Buildings USI 6. Employment and Housing Balance USI 7. Road Network Density USI 8. Demolition Management of Existing Buildings USI 9. Revitalize the Stock of Housing

Table 3. *Cont.*

Provisions	Indicators
Urban Infrastructure Improvement (UII) (8 indicators) Provision #8	UII 1. Heating Pipe Network Upgrades UII 2. Green Transportation UII 3. Waste Management System UII 4. Sponge Cities UII 5. Water-Saving Cities UII 6. Sewage Treatment System Renovation UII 7. Urban Lighting Management UII 8. Urban Green Spaces
Neighborhood Development (ND) (6 indicators) Provision #5	ND 1. Mixed Development ND 2. Comprehensive Residential Block Development ND 3. Walking and Cycling networks ND 4. Green Neighborhoods ND 5. Zero-Carbon Neighborhoods ND 6. Renewable-Energy Vehicles

2.3. Chinese Carbon Peaking Instruments for the Construction Sector

The document, Chinese Carbon Peaking Instruments for the Construction Sector, evolved into the Action Plan for Carbon Dioxide Peaking before 2030, which is mentioned in Section 1.2 and Table 1. The Chinese Carbon Peaking Instruments for the Construction Sector included 22 policy instruments with broad coverage. Five provisions that related to the governance of government departments were excluded from the analysis in Table 2. The remaining seventeen policy instruments were re-classified into different categories. The first categorization is "Scope" (i.e., the first column in Table 2), which re-classifies the seventeen provisions based on the scope of application. Second, as mentioned in the above literature review, due to differences in economics and the infrastructural developments of various urban and rural regions, the corresponding carbon-peaking strategies adopted by these vastly different urban and rural regions also differ. Hence, the second column "Applied Geography" re-classifies the provisions into "urban" or "rural" based on the geographical application, which is demonstrated in the document. The third is "Actors", which refers to who should respond and implement the corresponding provisions. Planners were identified as the practitioners for Provisions #4 and #8 (urban planning), Provisions #12 (rural planning), and Provision #5 for urban neighborhood planning.

2.4. Screening for Urban Planning and Neighborhood Development

In terms of the screening process (i.e., to set up the inclusion and exclusion criteria to select the relevant policy provisions for study), first, the source was the provisions contained in the governmental document, "*The Chinese Carbon Peaking Instrument for the Construction Sector (*Section 1.2*)*". Second, the inclusion criteria were as follows: (1) In this study, our research focus was limited to urban areas, because more than 80 percent of carbon emissions come from cities [7,18–20]. (2) Second, the minimum scale was limited to the urban neighborhood, because it is the fundamental building block of a Chinese city, and larger scales are urban districts and cities. This is because this study is focused on developing an assessment tool for low-carbon urban and neighborhood planning, as well as the inclusive provisions applied for urban and neighborhood planning. (3) Concerning the exclusion criteria, provisions such as economics were excluded from this study. This study was focused on the design, planning, and operating instruments that are directly linked to carbon emission reduction in cities and urban neighborhoods.

2.5. Indicator System for Low-Carbon Cities and Neighborhoods of the Construction Sector

Table 3 shows the outcomes of the screening process—the included provisions of "the *Chinese Carbon Peaking Instruments for the Construction Sector*". Eventually, three provisions—*Provision #4: Urban Structure Improvement*, *Provision #8: Urban Infrastruc-*

ture Improvement, and *Provision #5: Green and Low-Carbon Neighborhoods*—were included in this study for the development of the assessment tool. Each of them was a sub-set of indicators; *Provision #4* included nine indicators, such as "*USI 1. Layout Planning*", "*USI 2. Population Density*", and "*USI 3. Green Corridors*"; *Provision #8* included eight indicators; and *Provision #5* included six indicators. The specifications following each of the indicators give detailed definitions of the indicators and the requirements for implementation. For instance, the implementation of "*USI 3. Green Corridors*" requires the actors to strengthen the overall layout of ecological corridors, landscape viewing corridors, ventilation corridors, waterfront spaces, and urban greenways, and the ecological corridors between the urban groups should be continuous and have a net width of no less than 100 m.

The twenty-three indicators were used to form an indicator system for the next step of the network development and analysis, as described in Section 3.

- Provision #4: Urban Structure Improvement

Provision #4 emphasizes that "optimizing the urban structure, functional layout, urban form, density, and construction methods" is critical to the reduction in carbon emissions.

- Provision #8: Urban Infrastructure Improvement

Provision #8 emphasizes that "systematized, intelligent, ecologically green construction and stable operation of infrastructure can effectively reduce energy consumption and carbon emissions."

- Provision #5: Green and Low-Carbon Neighborhoods

Provision #5 emphasizes that "the neighborhood is an important place to form a simple, moderate, green, and low carbon, civilized and healthy lifestyle."

3. Analysis

3.1. Analytical Network Development

The structure of the decarbonation route for low-carbon urban planning and neighborhood development was developed based on the ANP (Figure 4). The purpose of the selected policy document was to guide the building sector to implement those carbon peaking strategies; hence, the goal of this policy document was identified as "decarbonization". According to this goal, we defined two principles of decarbonization, which were "carbon-emission reduction" [30–32] and "carbon capture" [33–35], based on a review of the literature. The goal and the two principles formed the control layer.

The low-carbon indicators of the three provisions—urban structure improvement (USI), urban infrastructure improvement (UII), and neighborhood development (ND)—were hypothesized by the authors to have a direct correlation with the goal of "decarbonization". Hence, all twenty-three indicators could be divided into two clusters based on "carbon-emission reduction (CER)" and "carbon capture (CC)" for ANP analysis. After analyzing the interactions within the indicators, the authors confirmed that the indicators contained within the two clusters (i.e., carbon-emission reduction and carbon capture) were independent of each other. The interaction was mapped and expressed in the network. As can be seen in Figure 4, the carbon-emission reduction cluster consisted of eighteen indicators under USI, UII, and ND. On the other hand, the carbon capture cluster consisted of the remaining five indicators under USI, UII, and ND. In the network layer, the two clusters were self-related (self-looped) and inter-correlated. A self-loop was generated because some of the indicators in the same clusters were correlated. For instance, the indicator "*USI 1. Layout Planning*" influenced the indicator "*USI 7. Road Network Density*" in the "*Carbon-Emission Reduction*" system, forming a "self-loop". The indicator "*USI 1. Layout Planning*" influenced the indicator "*USI 3. Green Corridors*" under the system of "*Carbon Capture*", which resulted in a correlation between the clusters CER and CC. All the details of correlations between the indicators are listed in Table 4.

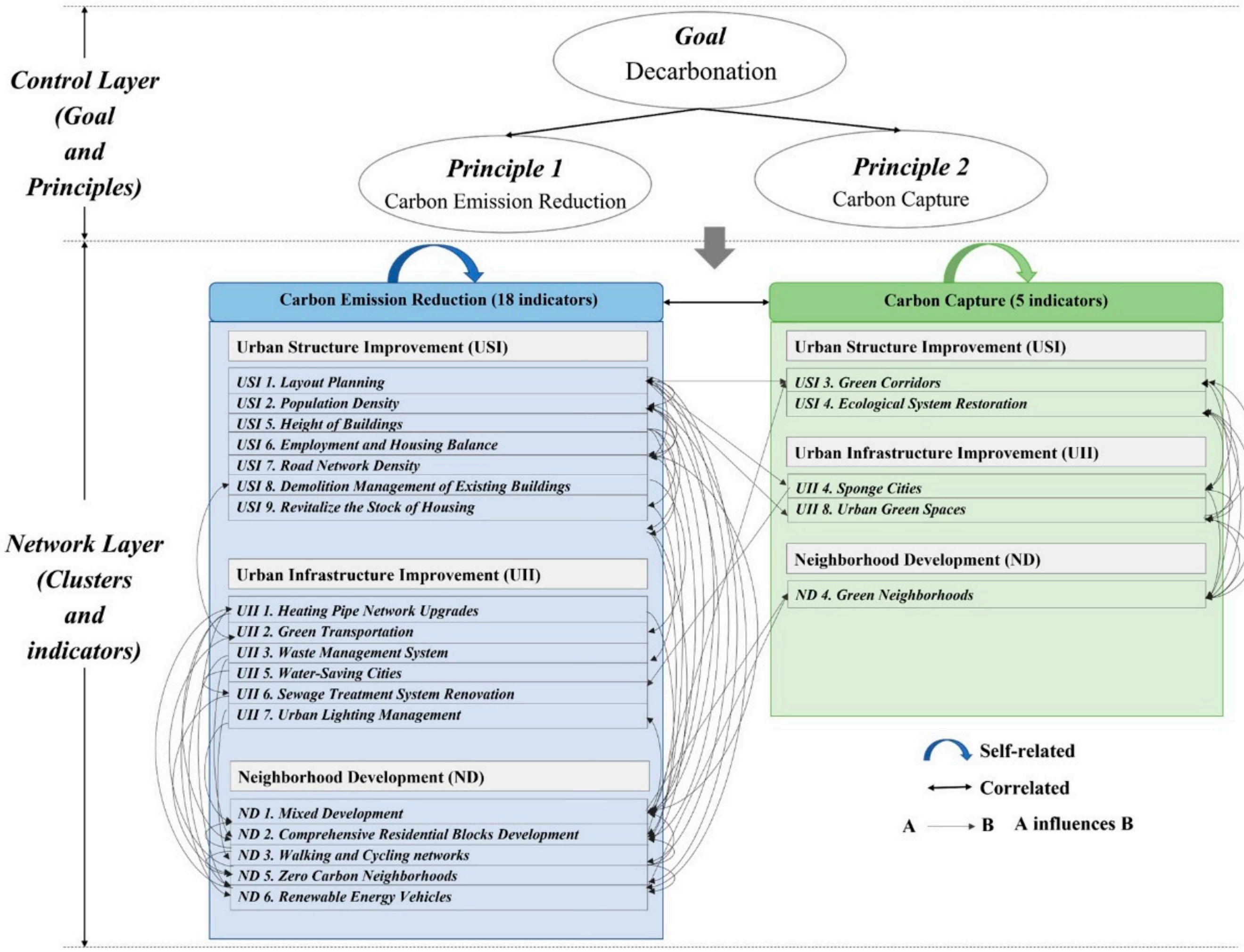

Figure 4. Structure of network for low-carbon urban and neighborhood planning based on the ANP (detail correlations between clusters and indicators refer to Table 4).

Table 4. Division of the indicators into two clusters, and the correlations between the indicators.

Cluster	Aspect	Indicator/Node	Influenced Factors
Carbon-Emission Reduction (CER System) (18 indicators)	USI	USI 1. Layout Planning	USI 2, USI 3, USI 7, UII 4, UII 8, ND 1, ND 2, ND 3, ND 5
		USI 2. Population Density	USI 1, USI 6, ND 1, ND 2, ND 5
		USI 5. Height of Buildings	USI 6, USI 8, ND 1, ND 2
		USI 6. Employment and Housing Balance	USI 1, USI 2, USI 9, ND 1
		USI 7. Road Network Density	USI 1, UII 2, ND 3
		USI 8. Demolition Management of Existing Buildings	UII 3
		USI 9. Revitalize the Stock of Housing	USI 2, ND 1, ND 2
	UII	UII 1. Heating Pipe Network Upgrades	ND 2, ND 5
		UII 2. Green Transportation	USI 7, ND 6
		UII 3. Waste Management System	ND 2, ND 5
		UII 5. Water-Saving Cities	UII 6
		UII 6. Sewage Treatment System Renovation	ND 5
		UII 7. Urban Lighting Management	ND 2, ND 5

Table 4. *Cont.*

Cluster	Aspect	Indicator/Node	Influenced Factors
Carbon-Emission Reduction (CER System) (18 indicators)	ND	ND 1. Mixed Development	USI 1, USI 2, USI 5, USI 6, ND 2, ND 4
		ND 2. Comprehensive Residential Block Development	USI 2, USI 3, USI 6, ND 3, UII 1, UII 7
		ND 3. Walking and Cycling Networks	USI 1, UII 2, ND 2, ND 5
		ND 5. Zero-Carbon Neighborhoods	USI 5, ND 2, ND 3, ND 4, ND 6, UII 1
		ND 6. Renewable-Energy Vehicles	UII 2, ND 4, ND 5
Carbon Capture (CC System) (5 indicators)	USI	USI 3. Green Corridors	UII 4, ND 4
		USI 4. Ecological System Restoration	UII 4, UII 8, ND 4
	UII	UII 4. Sponge Cities	UII 5, UII 8, ND 4
		UII 8. Urban Green Spaces	USI 1, USI 3, UII 4, ND 4
	ND	ND 4. Green Neighborhoods	USI 4, UII 4, UII 8

Noted: USI: Urban Structure Improvement; UII: Urban Infrastructure Improvement; ND: Neighborhood Development.

After defining the goal, the principles, the clusters, and the indicators of the system, the structural model of the CER cluster and the CC cluster were constructed in Super Decisions (SD) software for quantitative analysis (Figure 5). The interactions among the indicators/nodes were input into the model according to Table 4.

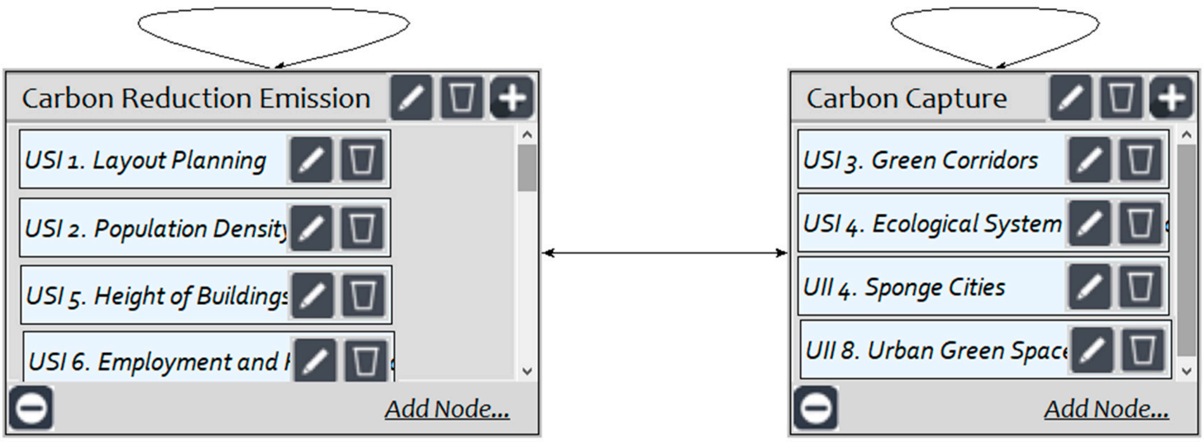

Figure 5. Structural model of the CER cluster and CC cluster based on the ANP.

3.2. Scoring and Calculations

3.2.1. Scoring Process

After the construction of the structure models, the counting of pairs among the indicators of the clusters (Table 5) and the judgment matrix was carried out. Pairwise comparisons were conducted to evaluate the degree of relevance of the twenty-three indicators to the two principles of decarbonation—*carbon-emission reduction* and *carbon capture*. An example of a question for each pairwise comparison is shown in Table 6, with x_i and x_j being the indicators. In the scoring system shown in Table 7, "one" means that the two indicators were equally relevant to *carbon-emission reduction* or *carbon capture*, whereas scores of "three" to "nine" indicate different degrees of relevance between the indicators and the principles. Formulas (1) and (2) refer to the comparison and the degree values. In this study, the ten authors included experts, scholars, planning, and architectural design practitioners, who discussed and inserted the scores of each of the pairwise comparisons into the Super Decision V3.2 software in order to generate an unweighted super matrix, a weighted super matrix, a limit matrix, and the priorities for quantitative analysis.

$$a_{ij} = x_i - x_j \tag{1}$$

where a_{ij} is the difference values of scores between x_i and x_j, and x_i and x_j are the indicators.

$$a_{ji} = 1/a_{ij} \tag{2}$$

where a_{ji} is the difference values of scores between x_j and x_i.

Table 5. The counts of pairs between indicators of the clusters.

		Influenced	
		Carbon-Emission Reduction	**Carbon Capture**
Influencing	Carbon-Emission Reduction	56	4
	Carbon Capture	1	13

Table 6. Example of the scoring questions.

Question	With Respect to USI 1. Layout Planning, USI 7. Road Network Density Is ___ ND 3. Walking and Cycling Networks.			
Indicator x_i		**Scores**		**Indicator x_j**
USI 1	9 8 7 6 5 4 3 2	1	2 3 4 5 6 7 8 9	USI 2

Table 7. Scoring the degree of relevance of indicators to the principles of *carbon-emission reduction/carbon capture*.

Score	Judgment
1	The two indicators are equally relevant to carbon-emission reduction/carbon capture
3	The former indicator is moderately more effective in carbon-emission reduction/carbon capture than the latter one
5	The former indicator is strongly more relevant to carbon-emission reduction/carbon capture than the latter one
7	The former indicator is very strongly more relevant to carbon-emission reduction/carbon capture than the latter one
9	The former indicator is extremely more relevant to carbon-emission reduction/carbon capture than the latter one
2, 4, 6, 8	The median value of the above adjacent judgments.

3.2.2. Priorities and Weighting Calculation

Table 8 and Figure 6 show the rankings of all twenty-three indicators based on the calculated weighting results. *USI 1. Layout Planning* occupied the first position in the ranking of all 23 indicators, at 15.9%. It was followed by *ND 5. Zero Carbon Neighborhoods*, at 10.5% of the total. The weighting of *ND 2. Comprehensive Residential Block Development* was slightly lower than that of ND 5, at 10.1%. At the bottom of the rankings, *USI 8. Demolition Management of Existing Buildings* and *UII 3. Waste Management System* exhibited the lowest weights, at 0.1% of the total, respectively. Based on the weighting results, a scorecard (rating system) was designed in order to evaluate the achievements of specific low-carbon urban and neighborhood planning strategies.

Table 8. Priorities and weighting of indicators.

Ranking	Indicators	Weighting	Percentage
1	USI 1. Layout Planning	0.159	15.9%
2	ND 5. Zero-Carbon Neighborhoods	0.105	10.5%
3	ND 2. Comprehensive Residential Block Development	0.101	10.1%
4	USI 2. Population Density	0.088	8.8%
5	USI 7. Road Network Density	0.060	6.0%
6	UII 2. Green Transportation	0.058	5.8%
7	ND 1. Mixed Development	0.053	5.3%
8	ND 4. Green Neighborhoods	0.047	4.7%
9	USI 6. Employment and Housing Balance	0.045	4.5%
10	UII 8. Urban Green Spaces	0.043	4.3%
11	UII 1. Heating Pipe Network Upgrades	0.040	4.0%
12	ND 6. Renewable-Energy Vehicles	0.039	3.9%
13	USI 4. Ecological System Restoration	0.029	2.9%
14	ND 3. Walking and Cycling networks	0.026	2.6%
15	USI 3. Green Corridors	0.024	2.4%
16	UII 4. Sponge Cities	0.022	2.2%
17	UII 5. Water-Saving Cities	0.019	1.9%
18	UII 6. Sewage Treatment System Renovation	0.019	1.9%
19	USI 9. Revitalize the Stock of Housing	0.008	0.8%
20	USI 5. Height of Buildings	0.007	0.7%
21	UII 7. Urban Lighting Management	0.006	0.6%
22	USI 8. Demolition Management of Existing Buildings	0.001	0.1%
23	UII 3. Waste Management System	0.001	0.1%

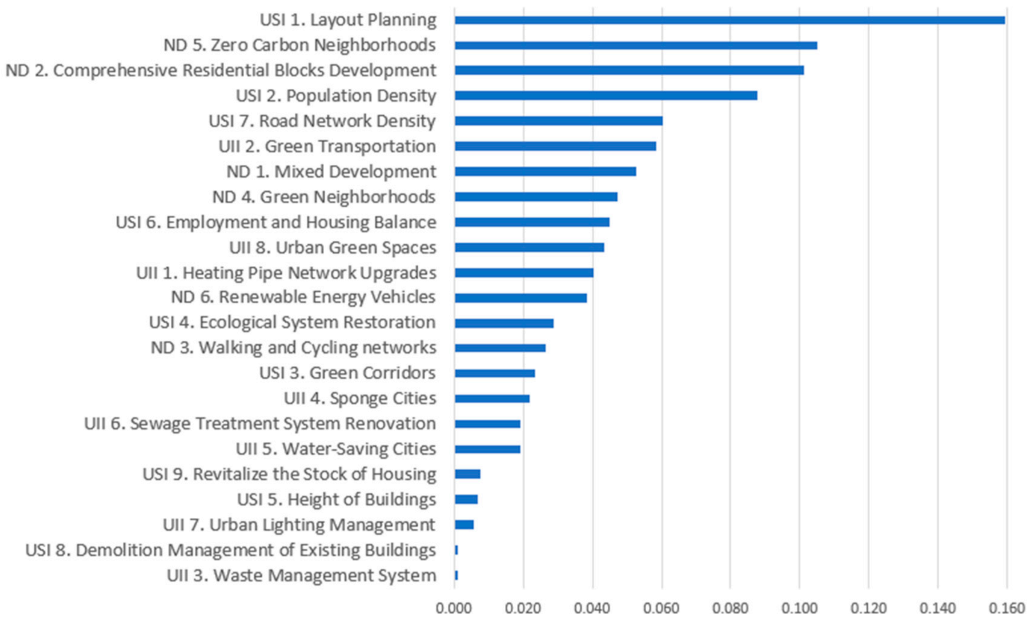

Figure 6. Rankings of indicators.

3.2.3. Credit System Development

According to the sum of the limiting values/a weighting of 1.0, the authors designed a total of 500 credits for the system, and further calculated the credits assigned to each indicator based on their weighting (Formula (3)). The sum of all the credits of the twenty-three indicators was 500 credits (Formula (4)). Calculation results are listed in Table 9, with the total credits of carbon-emission reduction amounting to 417.7, and the total credits of carbon capture amounting to 82.3, respectively. This scoring mechanism can help in the evaluation of the low-carbon planning strategies for actual projects. In the next section, we used two planning projects for the testing of this tool.

$$C_i = W_i \times 500 \tag{3}$$

$$\sum_{i=1}^{23} C_i = C_1 + C_2 + C_3 + \cdots C_{23} = 500 \tag{4}$$

where C_i is the credit value of each indicator, and W_i is the weighting of each indicator.

Table 9. Credits assigned to the indicators.

Cluster	Indicator/Node	Weighting	Credit	Total Credit
Carbon-Emission Reduction (CER) (18 indicators)	USI 1. Layout Planning	0.159	79.7	417.7
	ND 5. Zero-Carbon Neighborhoods	0.105	52.5	
	ND 2. Comprehensive Residential Block Development	0.101	50.5	
	USI 2. Population Density	0.088	43.8	
	USI 7. Road Network Density	0.060	30.1	
	UII 2. Green Transportation	0.058	29.2	
	ND 1. Mixed Development	0.053	26.4	
	USI 6. Employment and Housing Balance	0.045	22.5	
	UII 1. Heating Pipe Network Upgrades	0.040	20.1	
	ND 6. Renewable-Energy Vehicles	0.039	19.3	
	ND 3. Walking and Cycling networks	0.026	13.2	
	UII 5. Water-Saving Cities	0.019	9.6	
	UII 6. Sewage Treatment System Renovation	0.019	9.6	
	USI 9. Revitalize the Stock of Housing	0.008	3.8	
	USI 5. Height of Buildings	0.007	3.5	
	UII 7. Urban Lighting Management	0.006	2.9	
	UII 3. Waste Management System	0.001	0.5	
	USI 8. Demolition Management of Existing Buildings	0.001	0.5	
Carbon Capture (CC System) (5 indicators)	ND 4. Green Neighborhoods	0.047	23.6	82.3
	UII 8. Urban Green Spaces	0.043	21.7	
	USI 4. Ecological System Restoration	0.029	14.3	
	USI 3. Green Corridors	0.024	11.8	
	UII 4. Sponge Cities	0.022	10.9	
	Total	1.000	500	500

4. Discussion

4.1. Case Study—Practical Implementation in Urban Planning Projects

4.1.1. Basic Information for the Selected Cases

In this study, a new town planning project for a fourth-tier city, Wuzhou, is presented as Case A, and a neighborhood development project from the high-density city, Hong Kong, is selected as Case B. The basic information on the cases is given in Table 10. Both cases are located in the sub-tropical climate zone. Case A was a 6,000,000-square-meter new town planning project, whereas Case B was a 96,600-square-meter neighborhood development project.

4.1.2. Implementation of Indicators in the Selected Cases

Based on these equations, the credit scores of Case A and Case B were 322.2 and 193.3, respectively, out of a total of 500. As can be seen in Table 11, eleven indicators were scored for Case A, whereas nine indicators were scored for Case B. Figure 7 illustrates that the Indicator *USI 1. Layout Planning* contributed the most credits for Case A, and *ND 2. Comprehensive Residential Block Development* contributed the most credits for Case B. There were five overlapping credits achieved by the two cases, which shows that both cases applied the same strategies in project planning.

Table 10. Basic information for the studied cases.

Typology	New Town/District	Neighborhood
Selected cases	Case A	Case B
Aerial photos	 (Source: LWK + PARTNERS)	 (Source: LWK + PARTNERS)
Area (m^2)	6,000,000	96,600
Location	Wuzhou City, Guangxi Province	Tin Shui Wai New Town, Hong Kong
Latitude and longitude	111°34′ East, 23°51′ North	114°15′ East, 22°15′ North
City Scale	Fourth-tier city	High-density city
Climate Zone	Sub-tropical	Sub-tropical

Table 11. Credits acquired for Case A and Case B.

Provisions	Cluster	Indicator/Node	Credits Acquired	
			Case A	Case B
Urban Structure Improvement (USI) (9 items)	CER	USI 1. Layout Planning	79.7	-
		USI 2. Population Density	43.8	43.8
	CC	USI 3. Green Corridors	11.8	11.8
		USI 4. Ecological System Restoration	-	14.3
	CER	USI 5. Height of Buildings	3.5	3.5
		USI 6. Employment and Housing Balance	22.5	-
		USI 7. Road Network Density	30.1	-
		USI 8. Demolition Management of Existing Buildings	-	-
		USI 9. Revitalize the Stock of Housing	-	-
Urban Infrastructure Improvement (UII) (8 items)	CER	UII 1. Heating Pipe Network Upgrades	-	-
		UII 2. Green Transportation	-	-
		UII 3. Waste Management System	-	-
	CC	UII 4. Sponge Cities	10.9	10.9
	CER	UII 5. Water-Saving Cities	-	-
		UII 6. Sewage Treatment System Renovation	-	-
		UII 7. Urban Lighting Management	-	-
	CC	UII 8. Urban Green Spaces	21.7	21.7
Neighborhood Development (ND) (6 items)	CER	ND 1. Mixed Development	26.4	-
		ND 2. Comprehensive Residential Block Development	-	50.5
		ND 3. Walking and Cycling networks	-	13.2
	CC	ND 4. Green Neighborhoods	-	23.6
	CER	ND 5. Zero-Carbon Neighborhoods	52.5	-
		ND 6. Renewable Energy Vehicles	19.3	-
Total Credits		500	322.2	193.3

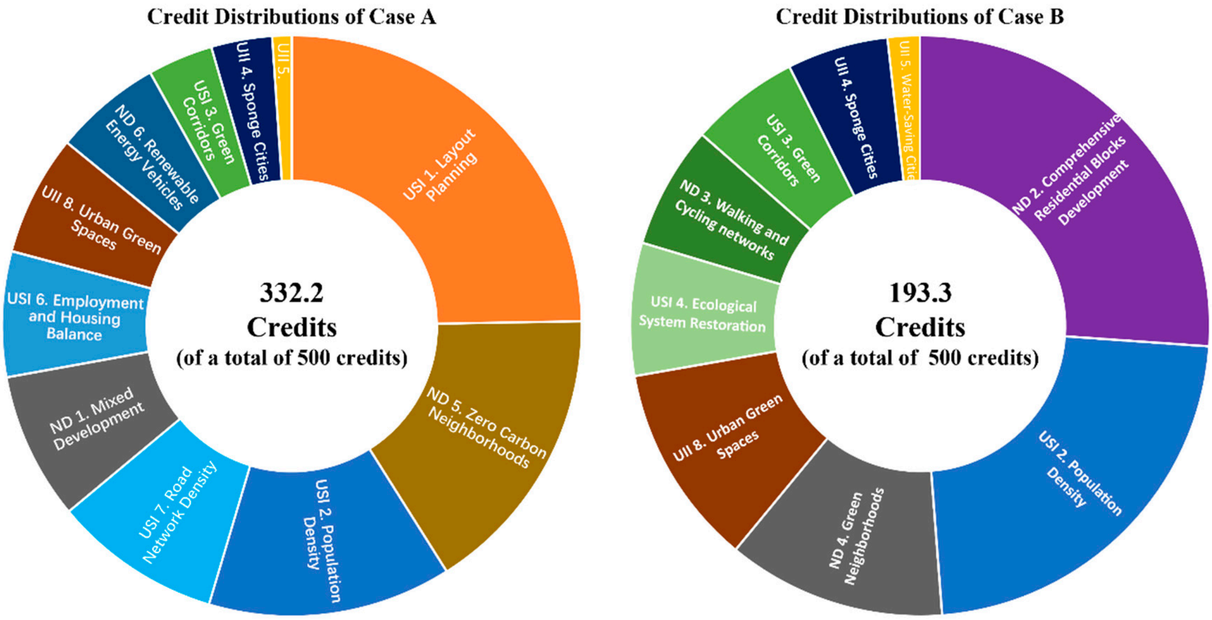

Figure 7. Credit distributions of Case A and Case B.

The planning strategies and implementation of indicators in Case A were identified as follows:

- Strategy 1—USI 1. Layout Planning—Create a suitable-scale new city group. The project site is surrounded by a river on the north side and a mountain on the south side, forming a relatively independent area with an area of about six square kilometers; small-scale urban group development can control the scale of urban construction land and provide better results.
- Strategy 2—USI 2. Population Density—Control the appropriate population density. The population density is 6300 people per square kilometer. The low population density reduces the development of construction land, and reserve more land for green space, water bodies, and roads to achieve green development goals.
- Strategy 3—USI 3. Green Corridors—Create themed greenway systems. The project aims to create two ecological greenways with the themes of mountains and water, respectively, with a total length of 15 km.
- Strategy 4—USI 5. Height of Buildings—Control the height of new buildings. The new residential buildings are mainly 6-storey, 11-storey, and 18-storey buildings.
- Strategy 5—USI 6. Employment and Housing Balance. In this project, the ratio of the employed population to the resident population is about 0.95/1. A higher employment-to-residential ratio reduces the distance required for transportation and commuting.
- Strategy 6—USI 7. Road Network Density—Increase the density of the urban road network. The plan involves a dense road network in small blocks, and the density of the urban road network within the planning scope will reach 8.3 km/km^2. Small blocks and dense road networks create vibrant streets, and slow-moving-friendly features reduce the carbon footprint associated with traffic and travel.
- Strategy 7—UII 4. Sponge Cities—Sponge city design and construction. The plan retains the mountain water system, respects the terrain and landforms of the plot, and aims to increase the area of green space, achieving 80% green space within the planning range (50% public green space, 30% garden greening), as well as increasing rainwater retention and utilization.
- Strategy 8—ND 1. Mixed Development—Promote the mixed development of urban functions. A residential development involves mixed land uses, such as commercial uses and offices, which promotes the development of blocks with mixed functions and emphasizes the integration of various functions in land use planning.

- Strategy 9—ND 5. Zero-Carbon Neighborhoods. The plan establishes public utility facilities within a 15 min walk of the residential areas to increase the proportion of green travel of residents and build a low-carbon and green travel community-life circle.
- Strategy 10—ND 6. Renewable Energy Vehicles—Promote the use of renewable energy vehicles.

Sufficient supporting renewable energy charging stations are designed to encourage the use of new energy vehicles.

The planning strategies and implementation of indicators in Case B were identified as follows:

- Strategy 1—USI 3. Green Corridors—Breezeway design. One 35 m principal breezeway and five secondary breezeways are included across the project site.
- Strategy 2—USI 2. Population Density/USI 5. Height of Buildings/ND 1. Mixed Development—Control the appropriate population density and the height of new buildings, and promote the mixed development of the project. The new residential buildings are mainly 10-storey towers, 5-storey villas, and 2-storey houses.
- Strategy 3—USI 4. Ecological System Restoration—Local plants and biodiversity. The project introduces 300 species and native species.
- Strategy 4—UII 8. Urban Green Spaces/ND 4. Green Neighborhoods—High green ratio. The green coverage of the project is 35%, and 1300 trees and 150,000 shrubs have been introduced.

4.1.3. Priorities of Indicator Selection in Project Practices

As can be seen from these two cases, indicators in both clusters were evident in these practical projects, with Case A enjoying a much higher score of 322.2 compared to that of Case B, at 193.3. The comparison shows that the planners and designers of the two projects respected the local conditions and responded to the limitations of the local conditions. The results reflected bias in the selection of indicators and the implementation of the strategies (Figure 8).

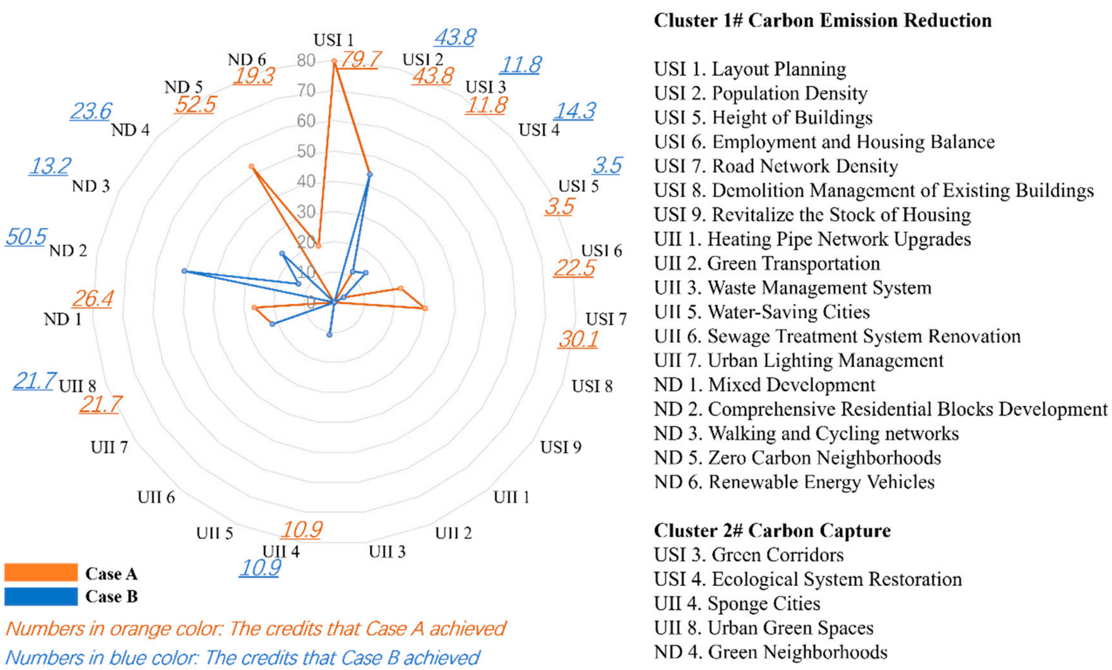

Figure 8. Comparisons of credit distributions of Case A and Case B. Note: The acquisition of credits for indicators in the radar chart was based on achievement, instead of performance; for details of the score table, see Table 11.

To further investigate the differences in the numbers of credits acquired and the credit distributions of the two cases, we further classified the indicators by decarbonation clusters (Table 12). As can be seen in the Credit Acquisition column, Case A acquired 277.8 credits by applying planning strategies grouped under the "carbon-emission reduction" cluster, whereas Case B only achieved 111 credits in the same cluster. The main reason for this is that the site area of Case A was significantly larger than that of Case B, at 6,000,000 square meters and 96,600 square meters, respectively. Hence, more low-carbon planning strategies sorted under the "carbon-emission reduction" cluster could be implemented in Case A. However, in the context of a well-developed high-density city, the focus of Case B was to perfect the protection of ecology and biodiversity and achieve a low-impact development within a limited site area. Hence, more low-carbon planning strategies under the cluster of "carbon capture" were applied in Case B, and the credits of Case B in the "carbon capture" cluster were almost double those of Case A, with 82.3 credits for Case B and 44.4 credits for Case A.

Table 12. Classification of indicators by decarbonation clusters.

Classification		No. of Indicators	Total Credits	Credits Acquired	
				Case A	Case B
Decarbonation	Carbon-Emission Reduction (CER)	18	417.7	277.8	111
	Carbon Capture (CC)	5	82.3	44.4	82.3
		Sub-total	500	322.2	193.3

4.2. International Assessment Tools Comparison and Indicators Benchmarking

In this part, benchmarking is conducted to further discuss the applicability of the Assessment Tool for Low Carbon Urban and Neighborhood Planning (LCUNP)—comparing it with the well-developed international assessment tools in other contexts. Benchmarking refers to comparing the findings with those validated and successful tools/standards. Hence, in this study, we select three international green rating systems for urban, district, and neighborhood planning—Singapore Green Mark for Districts (GM-D) [36], Japanese CASBEE for Urban Development (CASBEE-UD) [29], and LEED for Cities and Communities (LEED-CC) [37] for comparison.

The basic information on the selected assessment tools is shown in Table 13. Two of the international rating systems come from Asian countries (i.e., Singapore and Japan) and one comes from a Western country (i.e., The United States). In the scope of application, LCUNP and LEED-CC can be applied to assess the urban-scale, district-scale, and neighborhood-scale projects. In addition to urban, district, and neighborhood scales, GM-D and CASBEE-UD also include the assessment criteria for buildings. Furthermore, the biases of each tool can be seen from their credit distributions (Figure 9). Environmental planning strategies (i.e., Urban Structure Improvement, USI, and Environmental Planning, EP) take precedence in LCUNP and GM-D, and CASBEE-UD gives the same weightings to all the four parts, and the carbon emissions and energy-related strategies (EN) occupy most points in LEED-CC.

Table 14 shows the detailed benchmarking of the 23 indicators of the Assessment Tool for Low Carbon Urban and Neighborhood Planning (LCUNP) with the indicators in the selected international green rating systems (i.e., Green Mark, CASBEE, and LEED). For instance, the requirement of indicator *USI 1. Layout Planning* in LCUNP is similar to the indicator *EP 4-5 Site Selection* in GMD and *3.1.2. Urban structure* in CASBEE-UD. After the benchmarking process, we found that although the classifications are different—the LCUNP does not divide the 23 indicators into the water, energy, and other aspects—the criteria align still with the 23 indicators that can be found in the selected international assessment tools. Therefore, we believe that this finding has the property of general application in other contexts. It is worth noting that assessment tools for international applications should respect the local climate features, and cultures, as well as comply with national or local planning regulations and Codes. This is common sense in all the international green rating tools.

Table 13. Basic information of the selected assessment tools.

Tool/System		**LCUNP**	**GM-D**	**CASBEE-UD**	**LEED-CC**
Country		China	Singapore	Japan	America
Version		Version 1.0 (2022)	Version 2.0 (2013)	Version 2015	Version 4.1 (2019)
Scale(s)	Urban	√	√	√	√
	District	√	√	√	√
	Neighborhood	√	√	√	√
	Building	×	√	√	×
Aspects		1. Urban Structure Improvement (USI)	1. Energy Efficiency (EE)	1. Environment	1. Integrative Process (IP)
		2. Urban Infrastructure Improvement (UII)	2. Water Management (WE)	2. Society	2. Natural Systems and Ecology (NS)
		3. Neighborhood Development (ND)	3. Material and Waste Management (MWM)	3. Economy	3. Transportation and Land Use (TR)
			4. Environmental Planning (EP)	4. Environmental load of the urban development	4. Water Efficiency (WE)
			5. Green Buildings and Green Transport (GBGT)		5. Energy and Greenhouse Gas Emissions (EN)
			6. Community and Innovation (CI)		6. Materials and Resources (MR)
					7. Quality of Life (QL)

Table 14. Benchmarking and indicators alignment.

	Tools			
	LCUNP	**GMD**	**CASBEE-UD**	**LEED-CC**
Indicators	USI 1. Layout Planning	EP 4-5 Site Selection GBGT 5-2 Green Urban Design Guidelines	3.1.2. Urban structure	×
	USI 2. Population Density	×	3.2.1. Population	QL-Demographic Assessment
	USI 3. Green Corridors	×	1.2.2. Biodiversity (1.2.2.2. Regeneration and creation)	NS-Green Spaces
	USI 4. Ecological System Restoration	EP 4-7 Habitat Conservation and Restoration	1.2.2. Biodiversity (1.2.2.1. Preservation) S 2.2.1. Disaster prevention	NS-Ecosystem Assessment NS-Natural Resources Conservation and Restoration
	USI 5. Height of Buildings	×	×	×
	USI 6. Employment and Housing Balance	×	3.2.2. Economic development	QL-Affordable Housing

Table 14. *Cont.*

	Tools			
	LCUNP	**GMD**	**CASBEE-UD**	**LEED-CC**
Indicators	USI 7. Road Network Density	×	3.1.1. Traffic (3.1.1.1 Development of traffic facilities)	TR-Smart Mobility and Transportation Policy
	USI 8. Demolition Management of Existing Buildings	EP 4-6 Conservation and Integration of Existing Structures and Assets	1.1.2. Resources recycling (1.1.2.1. Construction)	MR-Construction and Demolition Waste Management
	USI 9. Revitalize the Stock of Housing	EP 4-6 Conservation and Integration of Existing Structures and Assets	3.2.2. Economic development (3.2.2.1. Revitalization activity)	QL-Affordable Housing
	UII 1. Heating Pipe Network Upgrades	EE 1-1 Energy Efficiency for Infrastructure and Public Amenities	×	EN-Energy Efficiency
	UII 2. Green Transportation	GBGT 5-3 Green Transport Within District	3.1.1. Traffic (3.1.1.1 Development of traffic facilities)	TR-Smart Mobility and Transportation Policy
	UII 3. Waste Management System	MWM 3-4 Waste Reduction MWM 3-5 Waste Management and Segregation MWM 3-7 Waste Reuse and Processing	1.1.2. Resources recycling (1.1.2.2. Operation)	MR-Solid Waste Management MR-Organic Waste Treatment MR-Smart Waste Management Systems
	UII 4. Sponge Cities	WM 2-2 Stormwater Management	1.1.1 Water resource (1.1.1.1 Waterworks)	WE-Stormwater Management
	UII 5. Water-Saving Cities	WM 2-1 Water Efficient Fittings for Infrastructure and Public Amenities WM 2-2 Stormwater Management WM 2-3 Alternative Water Sources 2-4 Water-Efficient Landscaping 2-5 Water Efficiency Management	1.1.1 Water resource (1.1.1.1 Waterworks)	WE-Integrated Water Management WE-Water Access and Quality WE-Stormwater Management WE-Smart Water Systems
	UII 6. Sewage Treatment System Renovation	MWM 3-5 Waste Management and Segregation MWM 3-7 Waste Reuse and Processing	En 1.1.1 Water resource (1.1.1.2 Sewerage)	WE-Wastewater Management
	UII 7. Urban Lighting Management	×	×	NS-Light Pollution Reduction
	UII 8. Urban Green Spaces	EP 4-2 Green and Blue Spaces for the Public	En 1.2.1. Greenery	NS-Green Spaces
	ND 1. Mixed Development	×	Ec 3.2.2. Economic development	TR-Compact, Mixed Use, and Transit OrientedDevelopment
	ND 2. Comprehensive Residential Block Development	EP 4-1 Self Sufficiency and Accessibility Within District	S 2.3.1. Convenience/welfare (2.3.1.1. Convenience)	QL-Affordable Housing
	ND 3. Walking and Cycling networks	GBGT 5-3 Green Transport Within District	S 2.3.1. Convenience/welfare (2.3.1.1. Convenience)	TR-Walkability and Bikeability TR-Access to Quality Transit
	ND 4. Green Neighborhoods	GMD 4-2 Green and Blue Spaces for the Public	En 1.2.1. Greenery	NS-Green Spaces

Table 14. *Cont.*

	Tools			
	LCUNP	**GMD**	**CASBEE-UD**	**LEED-CC**
Indicators	ND 5. Zero-Carbon Neighborhoods	GMD 1-2 On-site Energy Generation GMD 1-3 Site Planning and Building Orientation GMD 1-4 Energy Management System GMD 1-5 Minimize Energy Consumption During Off-Peak Hours	En 1.3.1. Environmentally friendly buildings	EN-Power Access, Reliability, and Resiliency EN-Energy and Greenhouse Gas Emissions Management EN-Energy Efficiency EN-Renewable Energy
	ND 6. Renewable-Energy Vehicles	×	×	TR-Alternative Fuel Vehicles Renewable Energy

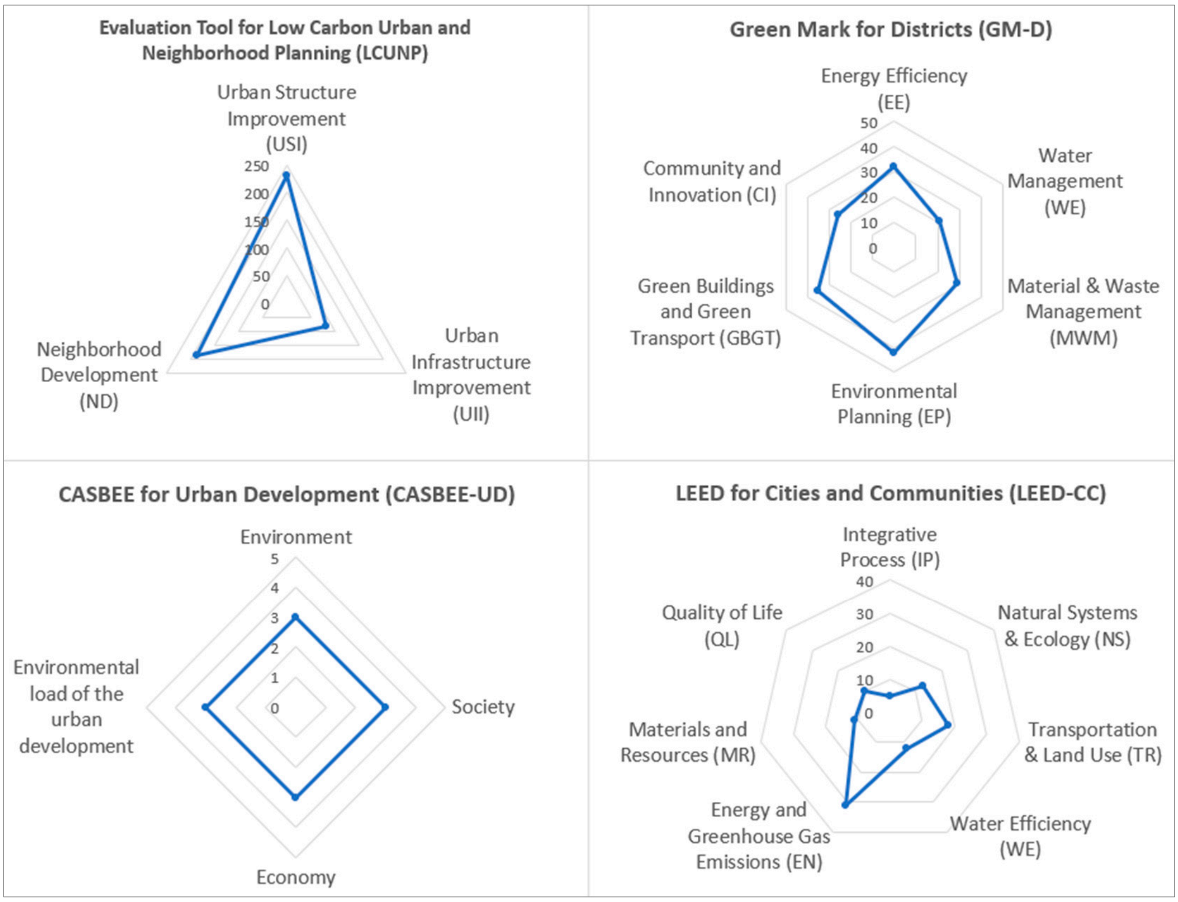

Figure 9. Credit distributions of the selected assessment tools.

5. Conclusions

In this study, we have developed a preliminary version of an assessment tool for low-carbon urban and neighborhood planning based on the three selected provisions from the Chinese Carbon Policy Document on the Building and Construction Sector. Each of the provisions represents a sub-set of indicators, with a total of twenty-three indicators forming the pool for the development structure and analysis. According to the goal identified in this document—decarbonization—we identified "carbon emission reduction" and "carbon capture" as the two principles, as well as the clusters, for analysis.

The analytical network process (ANP) was deployed in this study for the development of the network structure and quantitative analysis. In the results, the priorities and weighting of all the twenty-three indicators were based on their relevance to carbon-emission reduction or carbon capture. A scorecard (credit system) was designed to evaluate the achievements of low-carbon urban and neighborhood planning strategies. In our discussion of the results, the practical implementation of the tool was tested using two cases. The results demonstrated that the tool could be used effectively to evaluate the achievements of planning strategies with the aim of decarbonation in real projects, at the same time revealing the biases of specific low-carbon planning strategies interacting with different project requirements and limitations. Moreover, the international assessment tools comparison and indicators benchmarking process indicate that the *assessment tool for low-carbon urban and neighborhood planning* has general application properties in other contexts. This study contributes to the transformation of government policy documents into practical assessment tools for project evaluations. Moreover, this study demonstrates a workable methodology that policymakers can use to translate their policies into downstream applications, such as developing evaluation systems, standards, or codes of practice.

This assessment tool has so far been focused on the goal of decarbonation; hence, the standard of measurement was limited to evaluating the degrees of achievement obtained by means of planning and design strategies. Secondly, the scoring process in this study was carried out by the authors. Although there were experts, scholars, and urban planning practitioners included in the team, with a total of ten people, in future studies we will invite more experts from the field, as well as residents/occupants, to discuss and vote, in order to further enhance the weighting and scoring mechanism of the tool. Thirdly, the influencing factors were not accounted for in the development of this tool, and the acquiring of credits depended on indicator achievement, not performance. In terms of case study, more international cases need to be included in future studies to further improve the tool.

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Appendix A

Table A1. Specifications of the included indicators.

Provisions	Indicators	Specifications
Urban Structure Improvement (USI) (9 indicators) Provision #4	USI 1. Layout Planning	Actively carry out green and low-carbon city construction and promote urban group development. The area of each urban group should be no more than 50 square kilometers.
	USI 2. Population Density	Control the appropriate population density; the average population density in the urban group should be no more than 10,000 people/square kilometers in principle, and the maximum population for individual sections should be no more than 15,000 people/square kilometers.
	USI 3. Green Corridors	Strengthen the overall layout of ecological corridors, landscape viewing corridors, ventilation corridors, waterfront spaces, and urban greenways. The ecological corridors between urban groups should be continuous and have a net width of no less than 100 m.

Table A1. *Cont.*

Provisions	Indicators	Specifications
Urban Structure Improvement (USI) (9 indicators) Provision #4	USI 4. Ecological System Restoration	Improve the urban ecological system.
	USI 5. Height of Buildings	Strictly control new super-high-rise buildings, and generally introduce no new high-rise residential buildings.
	USI 6. Employment and Housing Balance	New urban areas should reasonably control the proportion of jobs and housing and promote a balanced and integrated distribution of employment and residential space.
	USI 7. Road Network Density	Reasonable layout of urban rapid trunk traffic, living distribution traffic, and green slow traffic facilities; the density of the road network in the main urban area should be greater than 8 km/square kilometer.
	USI 8. Demolition Management of Existing Buildings	The demolition management of existing buildings should be strictly implemented, and urban renewal should be promoted from "demolition, modification, and retention" to "retention, modification, and demolition". Except for illegal buildings and buildings identified by professional institutions as dangerous buildings with no repair or retention value, the current buildings should not be dismantled on a large scale and in a large area. In principle, the demolished building area in urban renewal units (areas) or projects should not be greater than 20% of the current total building area.
	USI 9. Revitalize the Stock of Housing	Revitalize the stock of housing and reduce all kinds of vacant housing.
Urban Infrastructure Improvement (UII) (8 indicators) Provision #8	UII 1. Heating Pipe Network Upgrades	Implement the renovation projects for the old heating pipe network that are more than 30 years old and strengthen the heat preservation materials of the heating pipe network. By 2030, the heat loss of the urban heating pipe network should be reduced by 5% compared with the 2020 baseline.
	UII 2. Green Transportation	Carry out special actions to purify sidewalks and build special bicycle lanes and improve supporting facilities such as connecting corridors and underground passages between urban rail transit stations and surrounding buildings. Increase the construction of special urban bus lanes, improve the operational efficiency and service level of urban public transport, and steadily increase the proportion of urban green transport trips.
	UII 3. Waste Management System	Implement waste classification, reduction, and recycling, and improve the system for sorting, collecting, transporting, and processing domestic waste. By 2030, the utilization rate of urban domestic waste should reach 65%.
	UII 4. Sponge Cities	Combined with the characteristics of the city, fully respect nature, strengthen the effective connection between urban facilities and the original ecological background of rivers and lakes, adjust measures to local conditions, and systematically promote the construction of sponge cities in the entire area. By 2030, the average permeable area of urban built-up areas across the country should reach 45%.
	UII 5. Water-Saving Cities	Promote the construction of a water-saving city, implement the renewal and reconstruction of the old urban water supply pipe network, promote the district metering of the pipe network, improve the intelligent management level of the water supply pipe network, and strive to control the leakage rate of the urban public water supply pipe network within 8% by 2030.
	UII 6. Sewage Treatment System Renovation	Implement the renovation of sewage collection and treatment facilities and the utilization of urban sewage resources by 2030. The average utilization rate of recycled water in cities across the country has reached 30%. Accelerate the renovation of urban gas supply pipelines and facilities.
	UII 7. Urban Lighting Management	Promote urban green lighting; strengthen the management of the whole process of urban lighting planning, design, construction, and operation; and control excessive lighting and light pollution. By 2030, the use of LED and other high-efficiency energy-saving lamps should account for more than 80%, and more than 30% of cities should have digital lighting systems.

Table A1. *Cont.*

Provisions	Indicators	Specifications
Urban Infrastructure Improvement (UII) (8 indicators) Provision #8	UII 8. Urban Green Spaces	Improve the urban park system, promote the construction of greenway networks in central and old urban areas, strengthen three-dimensional greening, and increase the application ratio of local and local suitable plants. By 2030, the green space rate in urban built-up areas should reach 38.9%. The built-up area has a greenway with a length of more than 1 km per 10,000 people.
Neighborhood Development (ND) (6 indicators) Provision #5	ND 1. Mixed Development	Promote mixed blocks with multiple functions and advocate a mixed layout of residential, commercial, and pollution-free industries.
	ND 2. Comprehensive Residential Block Development	Basic public service facilities, convenient commercial service facilities, municipal supporting infrastructure, and public activity spaces should be built, and the coverage of complete residential communities in cities at the prefecture level and above should increase to more than 60 percent by 2030.
	ND 3. Walking and Cycling networks	Connect residential communities through walking and cycling networks to construct a 15 min community-life circle.
	ND 4. Green Neighborhoods	Promote the creation of green neighborhoods; incorporate the concept of green development throughout the entire process of neighborhood planning, construction, and management; and 60% of urban neighborhoods should meet these creation requirements first.
	ND 5. Zero-Carbon Neighborhoods	Explore zero-carbon neighborhood construction.
	ND 6. Renewable-Energy Vehicles	Promote the use of renewable-energy vehicles and build community purging electrical infrastructure.

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