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Construction of a Low Carbon Eco-City Index System Based on CAS Theory: A Case of Hexi Newtown in Nanjing, China

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Abstract**—**The practice of urban planning and construction based on the concept of the "low carbon eco-city" has been universally accepted by the academic community in response to urban issues such as population, resources, environment, and social development. Based on this, the current article first analyzes the concepts of low carbon eco-city, then builds a complex adaptive system (CAS) theory based on Chinese traditional philosophical thinking, and analyzes the adaptive relationship between material and non-material elements. A three-dimensional evaluation model of natural ecology, economic low carbon, and social harmony was constructed. Finally, the construction of a low carbon eco-city index system in Hexi Newtown of Nanjing was used as an example to verify the effectiveness of the research results; this paradigm provides a new way to achieve a low carbon eco-city system.

Keywords**—**Complex adaptive system, low carbon ecology, index system, model.

I. Introduction

THE problems shown in the rapid urbanization process in China, such as city blind expansion, ecological imbalance, air pollution, traffic congestion, housing, social stratification has become more serious, and even has a serious impact on the development of China's urbanization quality, social harmony and sustainability. In recent years, city planning builders continue to explore, including the "healthy city" and "green city", "city toughness" and "wisdom city" from different perspectives and methods put forward to solve the present stage of urbanization in some of the problems encountered, continue to explore the mode to realize the sustainable development of the new town [1]. "Low carbon city" and "ecological city" after years of exploration and practice of concept planning and construction, has been proved very fruitful, and the two complement each other, "harmony but not sameness", the coordination of ecological city, paying attention to the natural environment and living environment, promote a more healthy and beautiful city life [2]; a low carbon city is concerned about climate change and the problem of energy waste, and the most direct purpose is to reduce carbon emissions, increase carbon sequestration [3]. The low carbon city and the ecological city are highly consistent in achieving the sustainable development of the city and the overall goal of improving peoples' environments. At the 2009 International Conference on Urban Development and Planning, Qiu Baoxing, the Vice Minister of the Ministry of Housing and Urban Rural Development, referred to the two as the "low carbon eco-city" [4], aiming at fully implementing the sustainable urban livable development thought.

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II. Research Progress of Low Carbon Eco-City

Since the concept of low carbon eco-city emerged, many regions at home and abroad have proposed to build their own low carbon eco-city and functional areas, including the foreign Masdar Eco-city in Abu Dhabi, the ecological city of Lake Hamomoby in Sweden, Turku, Finland, the Sino-Singapore Tianjin Eco-City, Caofeidian low carbon Eco-city, etc.. These cities have achieved good results in low carbon ecological construction. From these successful low carbon eco-city cases, we can see that the concept of low carbon eco-city focuses on the following aspects:

Firstly, the essential goal: The difference between low carbon eco-city and "garden city" and "green city" focuses on the opening of the internal ecological system, and pays attention to the coordinated development of ecology, economy, and society. It is a symbol of energy saving and environmental protection with low energy consumption, low pollution, and low emissions. Cities emphasize the efficient use and regeneration of physical energy rather than the environmental beautification movement. It is a new model of urban development with comprehensive balance of ecological environment [5]. It is a resource-saving, environment-friendly, suitable living environment, safe operation, and economic health. Development and people's livelihood continued to improve the city [6].

Secondly, system perspective: The low carbon eco-city is supported by advanced urban planning technology. It reorganizes and optimizes the "natural and man-made" system view of the natural environment, human settlement space, functional structure, infrastructure, and social structure in urban construction and avoids it. The conflict between ecological space and urban construction, realizing low carbon development as the central subsystem of the natural-economic-society complex ecosystem, and at the same time, the system has a gradually evolving regeneration function [7].

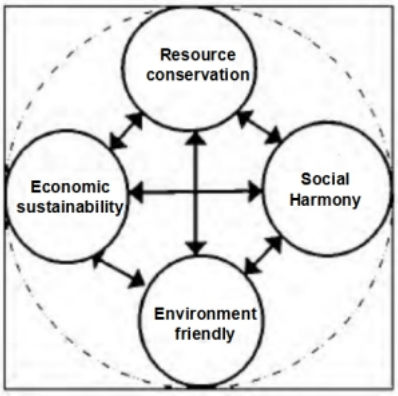

Fig. 1 Low carbon ecological analysis model of urban system

III. The Concept Model of the Low Carbon Eco-City System Based on CAS Theory

A. CAS Theory

For more than half a century near, the later-development countries, represented by China, have walked on a rapid industrialization and urbanization road, with a single pursuit of economic growth speed by neglecting the control of environmental costs and comprehensive benefits, which made structures of artificial natural ecosystems more and more simplex and unified. The living environment is divorced from the original ecology; then it has become a simple and rough linear superposition and combination, which result in a series of urban ecological and environmental problems, such as climate warming, fog and haze, flood disasters, water safety and diseases. Confronting these problems, many attempts have been made in the previous practices which include strengthening infrastructure, increasing the road area to solve traffic congestion, increasing the density of the main river network to alleviate the pressure of flood and strict sectorization of cities and so on. Until Bertalanffy put forward the core concepts of complexity science in the book The General System Theory: Foundation, Development and Application, the planning community began to pay attention to systematic concepts of system, whole, wholeness, emergence, diversity, connectivity and so on, which are used to try to examine urban planning and construction from a holistic perspective. Santa Fe Institute proposed some complexity concepts such as CAS, emergence, edge of chaos, increasing returns and path-dependence [8]. The scientists of China represented by Tsien Hsueshen defined a concept as open complex giant system from the perspective of system science [9].

A CAS tries to find the best solution for the whole, in the complexity theory it is thought that the local optimum is subordinated to the overall optimum, sometimes even by sacrificing local interests. At the same time, it tries to find some local intervention which makes the whole best but at least to maintain the local original body by using a thinking model of whole to local, and then back to whole.

The complex system consists of two major modules: the physical adaptive system model and the immaterial adaptive system model, with two aspects for analysis as macro aspect and micro aspect. The macro aspect is that paying attention to the hierarchy, diversity and aggregation degree of the subject, and emphasizing the continuous development or evolution of the system caused by the interaction between the subject and the natural environment; the same as the interaction between individuals and that between the individual and the environment. The micro aspect is that emphasizing the initiative and adaptability of the system, which means that by the nonlinear interaction between the various subjects, a subject keeps learning knowledge, accumulating experience and finally accomplish self-transformation - the individual's active adaptability.

CAS is one of the theories of complexity system, which provides a new idea for us to know, understand and control the nonlinear and complex things as the urban system [10]. Therefore, we should pay special consideration to the attention and exploration of the complexity theories when constructing a low carbon eco-city, as well as focus on the application of the complexity model. Therefore, it is the primary basis to understand the complexity of the low carbon eco-city to construct a low carbon eco-city evaluation model and index system. At the same time, a subject is significantly influenced by the random factors in the process of carrying out its behavior, which lead to constant changes of the structure of the organization and the behavior mode of the system. Therefore, the advantages and the keys of the CAS theory are the processing and operation methods of the random factors, then the CAS simulates the possibility and potential of the ecosystem, the biological system, the economic system, the social system and so on, and constantly modifies and improves its behavior patterns, in order to better adapt to the environment and to survive and develop [11], [12]. The framework of the low carbon eco-city index system worked out by using CAS is as shown in Fig. 2.

B. Construction of Low Carbon Eco-City Evaluation Model Based on CAS Theory

This paper uses the analytic hierarchy process to reconstruct the low-carbon eco-city three-dimensional evaluation model to guide the construction of low-carbon eco-city index system. The X, Y, and Z axes of the following figure represent the environmental ecological dimension, the economic low-carbon dimension, and the social harmonious dimension, respectively. M^0_t (X_0, Y_0, Z_0) is the critical point of the low-carbon eco-city at time t. The space enclosed by $X \geq X_0$, $Y \geq Y_0$, and $Z \geq Z_0$ is the low-carbon eco-city; M^T is the ideal state of T City, OM is the best way for cities to achieve low carbon ecology. For the three subsystems of the environment, economy, and society of the urban system, the first-class classification index of the three macro-levels of ecological index, low-carbon index, and harmonious index is constructed, and a scientific and reasonable subsystem is selected as a quantitative evaluator under each dimension [13]. Indicators give weight to the development conditions and conditions of the current conditions in the region.

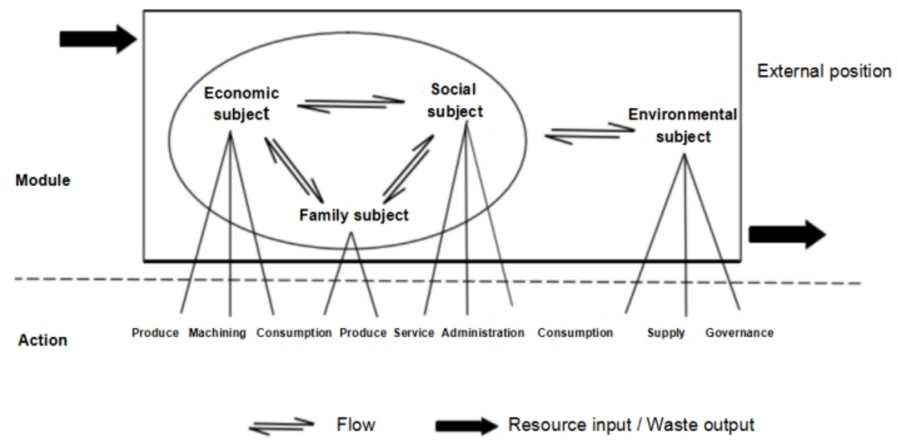

Fig. 2 The Module Structure of Low Carbon Eco-City's CAS

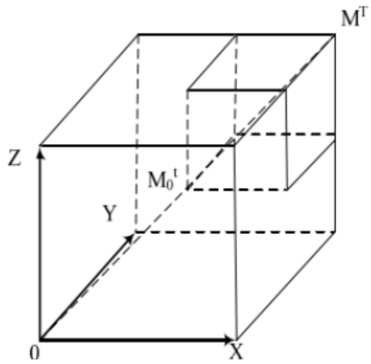

Fig. 3 Low Carbon Eco-City index evaluation of 3D model

Based on the three dimensional target process evaluation index system of low carbon eco-city built above, the urban ecological index, low carbon index and harmony index were calculated by weighted unified method and numerical unified unit.

$$\text{xg}=\sum_{i=1}^{3} Pxi \cdot Vxi$$

$$\text{yg}=\sum_{i=1}^{3} Pyi \cdot Vyi \quad (1)$$

$$\text{zg}=\sum_{i=1}^{3} Pzi \cdot Vzi$$

Among them, P_{xi}, P_{yi}, P_{zi} are divided into score values of the standard layer, and V_{xi}, V_{yi}, V_{zi} are divided into standard layer weights, i=1, 2, 3. The score value of the standard layer is calculated by the weighted average of the index under which it belongs, and the calculation formula is as follows:

$$\text{P} = \sum C \cdot W \quad (2)$$

P is the score value of the standard layer, and C is the norm value under the standard layer, and W is the weight of the index relative standard layer. The urban development status determined by the calculated value of three index evaluation values of X_g, Y_g and Z_g is an effective measure of urban low carbon ecology [14].

IV. Construction of Low Carbon Ecological Index System in Nanjing Based on CAS Theory

Nanjing Hexi New Town, located between New River and the Yangtze River in Qinhuai, is on the brink of the Yangtze River, and its ecological environment is superior. Three dimensional evaluation of low carbon ecological model based on CAS theory, determine the index framework by Delphy Fa and correlation analysis: (1) the Overall objective layer: ecological index, low carbon index and harmony index, a measure of low carbon eco-city natural ecological, economic and social well-being of the low carbon development level of 3 dimensions were used. Reflect the city system of the overall layout, structure, development scale and level. (2) The Standard layer: the key evaluation of the index of the target layer. The ecological index about the environment pleasant degree, ecological health and pollution prevention and control are effective; 3 aspects of low carbon index on rational use of resources, industry cycle efficiency and low carbon consumption patterns; harmonious index including public service system, the degree of perfection of social justice and social security three aspects. (3) Index layer: including the final determination of 32 specific indicators and weights [15], which are not directly related to each other, representing all aspects of the development of low carbon eco-city, as shown in Table I.

V. Innovation and Conclusion

Compared with other low carbon eco-cities which have been built at home and abroad, the low carbon eco-city of Hexi was started late, but it also allowed enough thinking space for scientific construction of the low carbon ecology index system of Hexi by using the CAS concept.

TABLE I
PARTS OF HEXI LOW CARBON ECO-CITY INDEX

Overall objective layer	Standard layer	Index layer	weight
Ecological index	Environmental pleasant indicators	Proportion of hard greening	0.04
		Separate garbage collection rate	0.03
		Water area ratio	0.03
		Utilization ratio of underground space	0.04
	Ecological health indicators	Proportion of public space	0.06
		Ratio of green space	0.07
		Species richness of greening objects	0.03
	Pollution prevention and control	Environmental investment index	0.02
		Noise pollution index	0.02
		Air quality index	0.03
		Water environment index	0.03
Low carbon index	Index of industrial cycle efficiency	Ratio of urban reclaimed water supply	0.03
		Ratio of industrial renewable energy	0.02
		Regenerated water capacity of unit building area	0.03
	Rationality of resource utilization	Energy utilization structure	0.05
		Ratio of renewable energy	0.03
		GDP energy intensity	0.03
		Proportion of low energy consumption industry	0.01
	Low carbon consumption pattern	Public transportation network density	0.05
		Public transport travel ratio	0.06
		Accessibility of public transport sites	0.03
		Proportion of commuting time is less than 1 hours	0.02
Harmony index	The degree of perfection of public services	Accessibility of the neighborhood center	0.03
		Coverage rate of 500 meters in primary schools	0.03
		Medical facilities ratio	0.02
		Proportion of pension facilities	0.02
	Social fairness	The number of employment accounts for the proportion of the total population	0.02
		The third industry accounts for the proportion of GDP	0.01
		Proportion of mixed land	0.05
	Public safety degree	Proportion of floating population	0.02
		Crime rate of residents	0.03
		Maximum difference between per capita income and minimum income	0.01

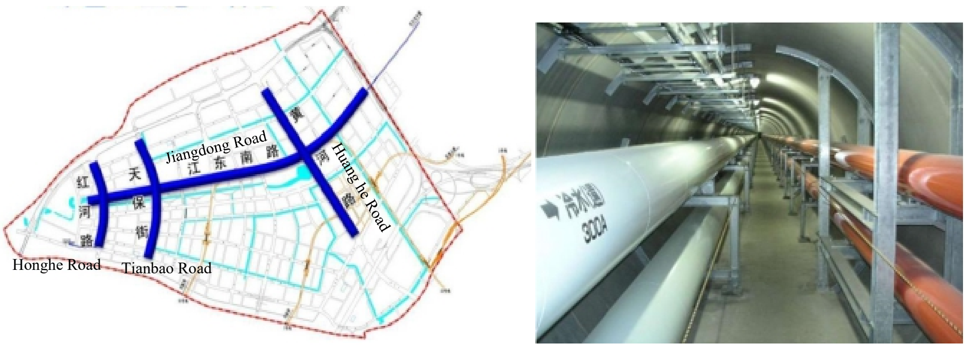

Fig. 4 Underground comprehensive pipe corridor of Hexi New Town

Fig. 5 Green Traffic and Garbage Classification Facilities of Hexi New Town

1) Net frame structure. The low carbon ecology index system of Hexi is divided into three levels as overall targets, criterions and indexes with three factors to control the indicators for each level; so that goals and control are both available. The horizontal index system ensures the completion of the indexes, and the vertical index system ensures the comprehensiveness of the indexes. 2) Comprehensive and efficient. It covers all aspects of Hexi low carbon eco-city, and avoids the complexity the of the indexes, and is easy to operate compared with the New TianJin Ecological Science and Technology City index system which has 22 control indicators and four guiding indicators, and the CaoFeiDian Ecological New-town index system which has 141 indicators of seven major subsystems. 3) Paying attention to details. According to the characteristics of the base of Hexi regional environment, we focus on the indexes of the hard land greening space, the regenerated water rate of building per unit, the recycling rate of garbage and so on, and make clear the specific requirements and the contents of the indexes, and to avoid being identical with other cities. 4) Making plans according to local conditions. We should seize the low carbon ecological land, the use of which is the basis of low carbon ecology, and optimize the public transport coverage and road network density to build a low carbon ecosystem program in a high density area. 5) Use of resources according to local conditions. Considering that Hexi district is near great rivers, rainwater recycling is considered in the near future and reclaimed water use is considered in the long term; considering there are thermoelectric plants and sewage treatment plants nearby, so the uses of ground source heat, river water heat, sewage source heat and solar energy are focused in energy use; at the same time, it is emphasized that the role of green building in the whole process of building a low carbon green city (design, construction, acceptance and operation) is important, and the national green building guidelines are revised according to local conditions.

This article is based on the analysis of the conceptual connotation of a low-carbon eco-city based on the innovative use of CAS theory to analyze the nonlinear relationships among the various elements of the urban complex system. The low-carbon eco-city target evaluation method obtained through the analytic hierarchy process has established an ecological system. Index, low-carbon index, and harmonious index are the index system frameworks used for overall measurement, effectively compensating for the static and single defects of most of the previous evaluation methods, and achieving a dynamic and multidimensional dimension balance measurement, facilitating the comparative evaluation of the low-carbon eco-city construction levels and Nanjing Hexi proved the validity and operability of the research results. With the improvement of low-carbon eco-city planning and construction technology, it is necessary to continuously adjust and update the indicators to include evaluation considerations, so as to ensure that the target evaluation system is objective and advancing with the times.

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