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Research on the Low-Carbon Development of Tourist Attractions Based on Complex Adaptive Systems Theory

—A Case Study of Yucun, Zhejiang Province

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Abstract

To achieve sustainable tourism, the low-carbon development of tourist attractions is particularly crucial. This study conducts an in-depth analysis of the low-carbon construction in Yucun, Zhejiang Province, based on the theory of Complex Adaptive Systems (CAS). By dissecting the application of seven CAS elements—aggregation, nonlinearity, flows, diversity, tags, internal models, and building blocks—during Yucun's low-carbon development process, the successful pathways to its low-carbon transformation are revealed. Building on this, the paper proposes specific recommendations for the low-carbon transition of other tourist spots, including collaborative innovation among diverse entities, strengthening low-carbon tags, stimulating nonlinear effects, optimizing the flow of information and resources, promoting diverse development, refining internal models, and constructing a building-block model for low-carbon development. This research provides systematic guidance and practical suggestions for constructing low-carbon tourist attractions, enriches the application of Complex Adaptive Systems theory in the field of low-carbon development, and offers a practical guide for global low-carbon tourist spot construction.

Keywords

Complex Adaptive Systems Theory, Tourist Attractions, Low-Carbon, Yucun, Zhejiang Province

1. Introduction

As the challenges of climate change intensify, the low-carbon economy has become a consensus for addressing global warming and protecting the ecological

environment (Nyambuu & Semmler, 2020). Against this backdrop, the tourism industry, as a vital component of economic development, has received widespread attention for its low-carbon transformation. Tourist attractions, as the core carriers of the tourism industry, play a crucial role in achieving sustainable tourism. Yucun "Two Mountains" scenic area, a 4A level tourist attraction in China, became one of the first low-carbon pilot villages in Zhejiang Province in November 2021. In 2022, China's Ministry of Ecology and Environment announced typical cases of green and low-carbon development, and Yucun's "Green, Low-Carbon, Shared-Prosperity" leisure-type low-carbon village model was successfully selected. Through a series of low-carbon measures, Yucun has successfully achieved a win-win situation for ecological and economic-social development, becoming a model for low-carbon tourist attraction construction. Therefore, studying the successful experiences of Yucun in low-carbon attraction construction has significant reference value for promoting the low-carbon transformation of other attractions.

Although existing studies have explored the concept of low-carbon scenic areas (Wu & Yuan, 2012), evaluation (Li & Yin, 2012; Cheng et al., 2013; Liu et al., 2020), driving mechanisms (Wang et al., 2019), low-carbon cognitive behaviors (Cheng et al., 2024), carbon emissions (Wang & Lyu, 2023), and development strategies (Li et al., 2013; Tong, 2022), there is still a lack of systematic analysis of low-carbon development at specific tourist spots. For instance, many studies focus on policy orientation, technological innovation, and public participation but lack a detailed discussion on how these factors interact in practice. This study fills this gap by employing Complex Adaptive Systems (CAS) theory to intricately analyze the specific practices during Yucun's low-carbon development, providing a framework to understand the interactions among diverse agents and their impact on the overall behavior of the system. This enables a better understanding and explanation of Yucun's successful low-carbon development pathways.

This paper first introduces the basic concepts and features of Complex Adaptive Systems theory, establishing that Yucun's low-carbon development is well-suited to be guided by CAS theory. It then analyzes the compatibility between Yucun's low-carbon development and CAS characteristics, followed by a detailed analysis of the seven CAS elements—aggregation, nonlinearity, flows, diversity, tags, internal models, and building blocks—applied during Yucun's low-carbon development. Based on Yucun's successful experience, specific recommendations for the low-carbon transformation of other tourist spots are proposed, aiming to provide references and lessons for the low-carbon development of attractions elsewhere. Finally, the paper concludes with a summary of the research.

2. Yucun's Low-Carbon Development under Complex Adaptive Systems Theory

2.1. Complex Adaptive Systems Theory

Complex Adaptive Systems (CAS) theory was first introduced by the American scholar Holland in 1994. Its core idea is that systems consist of proactive individuals

with adaptive capabilities, known as adaptive agents, which are the fundamental elements of a CAS. The driving force behind the continuous evolution of the system is the adaptability of its internal individuals, *i.e.*, "adaptability creates complexity". In a CAS, since adaptive agents possess adaptability and learning abilities, they form new processing rules through interaction and collaboration when faced with new "inputs", enhancing their own adaptability and thus increasing the system's complexity. The universality and openness of complex adaptive systems do not mean that it is suitable for any study; it is more appropriate when the system exhibits the characteristics of aggregation, nonlinearity, flows, diversity, tags, internal models, and building blocks.

2.2. The Practices of Low-Carbon Development in Yucun

By analyzing the compatibility of Yucun's low-carbon development with CAS characteristics, it is evident that Yucun's approach closely aligns with the fundamental features of a complex adaptive system (Table 1). Thus, Yucun's low-carbon development is well-suited to be guided by CAS theory for a comprehensive, full-process, integrative, and holistic study. This framework allows for a deeper understanding of how various adaptive strategies contribute effectively to sustainable and low-carbon outcomes in a dynamic and interconnected environment.

Table 1. Compatibility of Yucun's low-carbon development with the fundamental features of CAS Theory.

CAS Feature	Description of Feature	Compatibility Explanation with CAS Fundamental Features in Yucun's Low-Carbon Development
Aggregation	Individuals aggregate by "sticking together" to form a larger collective of multiple individuals.	During the low-carbon development of Yucun, stakeholders such as governments, enterprises, residents, and research institutions continually aggregate. These stakeholders spontaneously adopt adaptive behaviors and interact with each other, generating a series of economic, social, and environmental effects.
Nonlinearity	Individuals and their attributes do not follow a single linear relationship when changes occur.	In Yucun's low-carbon development, all stakeholders exhibit agency and learning ability, which means that their interactions do not follow simple linear relationships but are instead indeterminate and complex non-linear relationships.
Flow	Flow is a metaphor for the movement of matter, information, and energy among adaptive agents, enabling connections through the infusion, communication, and transformation of flows, which allows the system to develop.	Yucun's low-carbon development relies on the inflow, communication, and transformation of various resources such as financial flows, policy flows, information flows, and energy flows, facilitating the implementation and promotion of low-carbon projects.
Diversity	During the adaptation process, differences between agents can grow due to various reasons, ultimately leading to differentiation and promoting the system's diversification.	Diversity is the result and manifestation of agents' adaptive behaviors. Yucun enhances system adaptability and innovative capacity through diverse low-carbon projects and measures, such as low-carbon architecture, smart grids, and eco-tourism.
Tags	Facilitate selective interactions among agents, providing a basis for adaptive agents to identify whether to compete or cooperate.	Tags are the basis of agent interaction. Through policies, community norms, and environmental education, Yucun has developed a comprehensive low-carbon tagging system to guide the low-carbon behaviors of all stakeholders.

Continued

Internal Models	When receiving new information elements, agents choose appropriate behavioral models to respond to these changes, which are derived from experience and transformed into models for problem-solving.	In Yucun's low-carbon development, stakeholders have the capability to respond. Through ongoing environmental education and technical training, they enhance the low-carbon awareness and practical abilities of residents and businesses, optimizing internal models and improving adaptability.
Building Blocks	Systems are constructed from relatively simple components into more complex systems.	Yucun combines multiple simple low-carbon technologies and measures, such as solar power systems, smart grids, low-carbon buildings, and eco-agriculture, to construct a comprehensive and systematic low-carbon development model. The application of these building blocks not only enhances system adaptability and flexibility but also provides valuable references for other areas and attractions undergoing low-carbon transformation.

Data Source: Organized by the author.

2.2.1. Aggregation

In complex adaptive systems, aggregation refers to the formation of higher-level structures through the interaction and cooperation of similar entities. In Yucun's low-carbon development process, the collaborative cooperation of multiple parties has formed an integrated low-carbon development system. The local government, businesses, residents, and academic and research institutions are the primary agents of Yucun's low-carbon aggregation. Initially, the local government played a leading role in Yucun's low-carbon process. The Zhejiang Province and Anji County governments issued a series of policy documents supporting low-carbon development, providing the necessary funding and technical support to ensure smooth project implementation. For example, the "Yucun Zero Carbon Rural Construction Plan (2022-2035)" set clear targets and implementation paths for Yucun's low-carbon development. The government's policy support and financial investment provided strong guarantees for Yucun's low-carbon projects. Secondly, businesses also played a crucial role in Yucun's low-carbon process. The State Grid Zhejiang Electric Power Company deployed a smart grid system in Yucun, helping to optimize the allocation of electric power resources and enhance energy efficiency. In addition, businesses participated in specific project implementations, such as building rooftop solar power systems and the "Impression of Yucun" zero-carbon library. The active participation of residents was another key factor in the successful low-carbon transformation of Yucun. Residents not only installed rooftop solar panels but also actively participated in community low-carbon activities and environmental education. Through everyday low-carbon behaviors such as conserving electricity and waste sorting, residents contributed to the village's low-carbon development. The community guided residents to adhere to low-carbon living standards by establishing village rules and agreements. Furthermore, academic and research institutions played a significant role in Yucun's low-carbon process by providing technical advice and research support, helping to devise scientifically sound low-carbon development plans.

2.2.2. Tags

In complex adaptive systems, tags play a crucial role in guiding individual behavior. Yucun formed a comprehensive low-carbon tagging system through policies, regulations, and education, guiding the low-carbon behavior of all parties. In terms of policy and regulations, Yucun formulated and strictly enforced low-carbon development policies and regulations. For instance, the "Yucun Zero Carbon Rural Construction Plan (2022-2035)" specified detailed measures and requirements for energy conservation and emission reduction, ensuring that every villager could follow low-carbon living standards. These policies not only regulated residents' daily behaviors but also provided guidance and support for businesses and other entities' low-carbon projects. Regarding community norms, residents and tourists were guided to adhere to low-carbon behavioral guidelines through publicity and education. Yucun set up low-carbon lifestyle promotion boards within the village and regularly conducted low-carbon lectures and activities, enhancing community members' environmental awareness. Through these promotional and educational activities, the concept of low-carbon living became deeply ingrained, with residents and tourists actively participating in low-carbon actions. Moreover, Yucun also spread low-carbon knowledge to the public through initiatives like the zero-carbon science popularization base, further enhancing residents' and tourists' environmental consciousness and engagement.

2.2.3. Nonlinearity

Nonlinearity, a core feature of complex adaptive systems, refers to a system's output not being linearly related to its input. In Yucun's low-carbon development, this characteristic is fully demonstrated through pilot projects and demonstration projects. Yucun's low-carbon initiatives not only produced significant local effects but also, through demonstration, encouraged the implementation and promotion of more similar projects. Yucun pioneered the "Impression of Yucun" zero-carbon library, optimizing architectural design and employing photovoltaic technology to achieve carbon neutrality throughout its lifecycle. This project not only reduced energy consumption during building operations but also achieved negative carbon emissions through carbon offset measures. The zero-carbon library serves not only as a successful demonstration of Yucun's low-carbon projects but also as the first building in the country to receive both domestic and international platinum certifications for a rural lifecycle carbon-neutral structure, significantly enhancing Yucun's influence in the field of low-carbon architecture.

2.2.4. Flows

In complex adaptive systems, flows describe the exchange and transmission of information, resources, and energy within the system. In Yucun, the flows of information and resources have been fully optimized and utilized. Regarding information flow, Yucun leveraged digital technology and big data analysis to establish an intelligent digital twin system. This system links electricity usage data with carbon emission data, allowing for precise carbon emission collection and lean mana-

gement. This system not only enhances the accuracy of carbon emission monitoring but also provides a scientific basis for low-carbon management, aiding decision-makers in making more informed choices. Regarding resource flow, the promotion of renewable energy projects like rooftop solar panels has enabled Yucun to achieve energy self-sufficiency, reducing dependency on external energy sources. Additionally, the smart grid system optimizes the allocation of electrical resources, improving energy efficiency. For example, Yucun's public building rooftop solar projects and thin-film solar power systems not only meet local electricity demands but also integrate excess power into the grid, achieving efficient energy use.

2.2.5. Diversity

Diversity, an important feature of complex adaptive systems, refers to the variety of agent types, attributes, and behaviors within a system. Yucun has enhanced the system's adaptability and innovative capacity through diverse low-carbon projects and measures. In terms of low-carbon projects, Yucun has carried out diverse initiatives in areas such as low-carbon buildings, renewable energy, and smart grids. For instance, the construction of the "Impression of Yucun" zero-carbon library, rooftop solar panel projects, and smart grid systems not only covers multiple domains like architecture, energy, and infrastructure but also integrates different technologies and methodologies to enhance the overall low-carbon impact. In terms of measures, Yucun has formed a comprehensive low-carbon development system through policies, regulations, and education, ensuring that all agents can find paths suitable for their own low-carbon development. Furthermore, by developing eco-tourism and low-carbon agriculture, Yucun has further increased the diversity of low-carbon projects. For example, by utilizing abandoned quarries and cleared land for comprehensive tourism and under-forest economies, building ecological landscapes and emerging industries, Yucun promotes the integration of green industries.

2.2.6. Internal Models

Internal models refer to the perceptions and understandings of the environment constructed by system agents based on their own experiences and information. Yucun has continually optimized the internal models of residents and businesses through education and training, enhancing their low-carbon awareness and capabilities. In terms of environmental education, Yucun, through means like the zero-carbon science popularization research base, has spread low-carbon knowledge to residents and tourists, boosting their environmental awareness. For instance, Yucun regularly organizes low-carbon lectures and environmental education activities, using real-life cases and interactive experiences to deepen residents' and tourists' understanding of the importance and practical methods of low-carbon living. In terms of technical training, Yucun, in collaboration with businesses and research institutions, has provided low-carbon technology training to residents and businesses, enhancing their low-carbon skills and management abilities. For

example, Yucun collaborated with universities like Zhejiang University to offer a series of low-carbon technology training courses, covering topics such as solar power generation and smart grids.

2.2.7. Building Blocks

Building blocks, a key concept in complex adaptive systems theory, refer to the system's construction from relatively simple components into more complex systems. Yucun has formed a comprehensive and systematic low-carbon development model by combining multiple simple low-carbon technologies and measures. The key to this model lies in the organic integration of various low-carbon technologies and measures, forming a cohesive whole. For example, in promoting renewable energy, smart grids, and low-carbon buildings, Yucun has effectively integrated these technologies to create a more efficient and reliable low-carbon development system. Through the combination of solar power systems and smart grid technologies, Yucun has achieved self-sufficiency and efficient use of energy; through the promotion and optimized design of low-carbon buildings, carbon emissions have been reduced, and building energy efficiency has been enhanced.

In summary, Yucun's low-carbon development under complex adaptive systems theory, through multi-agent aggregation and collaboration, clear low-carbon tags, nonlinear interactions, efficient flows of information and resources, diverse low-carbon projects and measures, and optimized internal models, has built a comprehensive low-carbon development system. This system not only enhances Yucun's ecological and economic benefits but also provides a replicable low-carbon development model for other regions. By summarizing Yucun's successful experiences, valuable references can be provided for global low-carbon rural construction.

3. Low-Carbon Development Strategies for Tourist Attractions Based on Complex Adaptive Systems Theory

3.1. Aggregating Diverse Stakeholders to Promote Collaborative Innovation

In the process of advancing low-carbon transformation, establishing a mechanism for collaborative cooperation among diverse stakeholders is crucial. Local governments should enact and implement detailed low-carbon development policies and incentive measures, providing the necessary financial and technical support to ensure smooth project implementation. For example, creating a special low-carbon fund to finance low-carbon projects and technology research and development, offering tax incentives and subsidies, and encouraging businesses and residents to actively participate in low-carbon projects. Businesses should drive the application and dissemination of low-carbon technologies through technological innovation and project implementation, particularly by conducting in-depth research and application in fields such as renewable energy, smart grids, and energy-efficient construction. Communities and residents, as direct practitioners of a low-carbon lifestyle, should actively participate in low-carbon actions such as energy

conservation, waste sorting, and green transportation, enhancing their environmental awareness and involvement through community activities and educational campaigns. Additionally, academic and research institutions should play a role in providing technical and intellectual support by conducting low-carbon technology research, offering technical advice and training to help create scientifically sound low-carbon development plans, ensuring the scientific validity and feasibility of the projects. For instance, establishing industry-academic-research collaboration platforms could facilitate the transformation and application of scientific research results, jointly advancing the progress and dissemination of low-carbon technologies.

3.2. Strengthening Low-Carbon Labels to Enhance Public Awareness

In the process of low-carbon transformation, strengthening the low-carbon labeling system is crucial. Governments should develop and strictly enforce policies and regulations for low-carbon development, specifying clear measures and requirements for energy conservation and emission reduction to ensure that all stakeholders adhere to low-carbon living standards. Communities should establish low-carbon lifestyle information boards, regularly hold low-carbon lectures and activities to enhance the environmental awareness of residents and tourists. Establishing a zero-carbon education system, through zero-carbon science popularization bases, would help disseminate low-carbon knowledge to the public and utilize modern technological means such as virtual reality (VR) and augmented reality (AR) to provide immersive low-carbon experiences, allowing residents and tourists to more directly understand the significance and importance of a low-carbon lifestyle. Additionally, businesses can incorporate low-carbon labels into their products and services, conveying the low-carbon and environmental features of products to consumers through certifications and labels, thus promoting green consumption. By integrating big data and artificial intelligence technologies, develop applications for a low-carbon lifestyle that provide carbon emission monitoring, energy-saving suggestions, and low-carbon behavior incentive mechanisms, encouraging the public to actively participate in low-carbon actions.

3.3. Stimulating Nonlinear Effects to Drive Project Innovation

In the low-carbon transformation process, it is essential to fully leverage nonlinear effects by using pilot projects and demonstration projects to drive the implementation and promotion of more similar projects. Selecting pilot projects that are innovative and demonstrative can lead to the implementation of more similar projects through successful demonstrations. For example, in constructing zero-carbon buildings, smart grids, and renewable energy projects, emphasis should be placed on technological innovation and dissemination. By introducing advanced energy-saving technologies and management models, the overall benefits and sustainability of projects can be enhanced. Governments can establish low-carbon

demonstration zones to concentrate resources and technology for significant breakthroughs, using the successful experiences of these zones to drive low-carbon development in surrounding areas. Businesses should actively participate in technological innovation, promoting the application and dissemination of low-carbon technologies. By setting up low-carbon technology research and development centers and engaging in technical cooperation and exchanges, businesses can enhance their technological level and competitiveness. Integrating blockchain technology, establishing transparent management and monitoring systems for low-carbon projects can ensure effective implementation and management, thus increasing public trust and participation.

3.4. Facilitating Information and Resource Flow to Enhance System Efficiency

In the process of low-carbon transformation, optimizing and utilizing information and resource flows is key to enhancing system efficiency. It is essential to establish an intelligent information flow platform, using digital technology and big data analysis to build a smart digital twin system. This system should accurately link electricity usage data with carbon emission data for precise management and lean operations. This system not only improves the accuracy of carbon emission monitoring but also provides a scientific basis for low-carbon management, aiding managers in making more informed decisions. Regarding resource flow, promoting renewable energy projects is crucial to achieving energy self-sufficiency and reducing reliance on external energy sources. Smart grid systems should optimize the allocation of electrical resources, enhancing energy efficiency and ensuring stable supply during peak energy periods. Integrating Internet of Things (IoT) technology to develop a smart energy management system can achieve dynamic monitoring and optimal scheduling of energy, improving energy efficiency and management levels. Additionally, advancing a shared energy economy model is advisable, encouraging mutual assistance and sharing of energy among residents and businesses. Through energy trading platforms, efficient allocation and utilization of energy can be realized, promoting a more sustainable and cooperative energy landscape.

3.5. Promoting Diverse Development for Sustainable Transformation

Diverse development is a crucial pathway for achieving low-carbon transformation and sustainable growth. It is essential to employ a variety of low-carbon projects and measures to enhance the system's adaptability and innovative capacity. Diverse projects should be undertaken in areas such as low-carbon buildings, renewable energy, and smart grids, integrating various technologies and methods to enhance the overall low-carbon impact. The combination of policies, standards, and education can form a comprehensive low-carbon development system, ensuring that all stakeholders can find paths that are suitable for their own low-carbon development. For example, governments can enact comprehensive low-

carbon policies to drive the low-carbon transformation across all industries and sectors, promoting the optimization and upgrading of the economic structure. Developing eco-tourism and low-carbon agriculture, utilizing abandoned mines and cleared lands for comprehensive tourism and under-forest economies, constructing ecological landscapes and new business forms can foster the integration of green industries. These measures not only enhance the quality of the ecological environment but also increase villagers' incomes, promoting sustainable economic development. Additionally, the development of green finance should be encouraged, providing green loans and investments to support the implementation and development of low-carbon projects, thus facilitating a comprehensive advancement of the low-carbon economy.

3.6. Optimizing Internal Models to Enhance Adaptability

Optimizing internal models is a crucial method for enhancing low-carbon adaptability through continuous education and training, aimed at improving the low-carbon awareness and capabilities of residents and businesses. Comprehensive environmental education and training should be conducted, using zero-carbon science popularization bases and similar platforms to disseminate low-carbon knowledge to residents and tourists, thereby strengthening their environmental consciousness. Regular low-carbon lectures and environmental education activities should be organized, using practical cases and interactive experiences to deepen the understanding of the importance and practical methods of low-carbon living. Collaboration with businesses and research institutions should be pursued to provide systematic low-carbon technology training, enhancing the low-carbon skills and management capabilities of residents and businesses. For instance, conducting training sessions covering areas such as solar power generation, smart grids, and energy-efficient construction can help residents and businesses better adapt to low-carbon development requirements, enhancing their practical low-carbon capabilities and management skills. Moreover, establishing low-carbon communities to advocate for a green lifestyle through community activities and demonstration projects can guide residents and businesses to actively participate in low-carbon actions, thereby fostering a positive environment for low-carbon development.

3.7. Building a Modular Low-Carbon Development Model for System Integration

In the low-carbon transformation process, utilizing the concept of building blocks to combine multiple simple and efficient low-carbon technologies and measures into a comprehensive and systematic low-carbon development model is a crucial strategy for achieving sustainable development. Initially, in the utilization of renewable energy, it is recommended to broadly promote solar power systems, such as installing solar panels on public buildings and residential rooftops to achieve energy self-sufficiency. These solar panels, as simple building blocks, can signifi-

cantly enhance energy utilization efficiency through their widespread application and combination, reducing reliance on external energy sources and enhancing energy security. Additionally, constructing microgrid systems using smart grid technology to connect dispersed renewable energy generation equipment can create an efficient and reliable power supply network. The application of smart grids ensures stable power supply during peak energy periods, reduces power wastage, and optimizes the allocation of energy resources. Furthermore, promoting low-carbon buildings is another key element of the modular low-carbon development model. Advancing the use of green building materials and energy-saving designs, such as photovoltaic power generation, natural ventilation, and insulation materials, these simple yet effective architectural technologies can be combined to construct buildings with a full lifecycle carbon-neutral footprint.

4. Conclusion

This study, based on the Complex Adaptive Systems Theory, conducts an in-depth analysis of the low-carbon development of tourist attractions in Yucun, Zhejiang Province, revealing the intrinsic mechanisms and successful pathways of its low-carbon growth. The research finds that Yucun has constructed a comprehensive and systematic low-carbon development model through collaborative cooperation among multiple stakeholders, implementation of innovative low-carbon projects, efficient information and resource flows, diverse low-carbon measures, and educational training. This study holds significant theoretical and practical significance. Theoretically, this paper enriches the body of research on low-carbon development at tourist attractions; it also utilizes Complex Adaptive Systems Theory to provide an effective theoretical framework and practical guide for understanding and advancing the construction of low-carbon tourist attractions, thus broadening the application scenarios of the theory. Practically, the experiential insights proposed offer systematic guidance and specific operational suggestions for the low-carbon transformation of other tourist spots and rural areas. Overall, the findings of this study contribute to achieving the global goals for low-carbon development of tourist attractions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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