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Measurement of Carbon Emission Efficiency and Optimal Emission Reduction Pathways for Hainan's Tourism Industry Based on the DEA Method

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Abstract Hainan, as an important tourist destination, faces the dual challenges of fragile ecological environment and rapid development of tourism. Under the background of peak carbon neutral strategy, it is important to assess the carbon emission efficiency of Hainan tourism and optimize the emission reduction path. This study evaluates the carbon emission efficiency of Hainan tourism from 2013 to 2024 based on the entropy weight method and the super-efficiency-SBM model, analyzes the temporal and spatial evolution of the carbon emission efficiency by using the Markov chain, and proposes an optimization scheme of the emission reduction path. The results show that the carbon emission of Hainan tourism increases from 2,326,690,000 tons to 8,364,280 tons in 2013-2023, with a growth of 3.595 times, and decreases to 3,538,260,000 tons in 2024, with a decrease of 57.70%; the carbon emission intensity of the tourism industry decreases from 2.064 tons/yuan in 2013 to 0.427 tons/yuan in 2024, with a decrease of 79.31%. The carbon emission intensity of tourism will drop from 2.064 tons/yuan in 2013 to 0.427 tons/yuan in 2024, a decrease of 79.31%. From the perspective of spatial distribution, the carbon emission efficiency of the tourism industry in the eastern region of Hainan is higher than that in the central and western regions, but it is a “W”-shaped slow decline trend; the efficiency of the western region starts from a lower point but fluctuates and rises. Markov chain analysis shows that the convergence effect of the tourism industry's carbon emission efficiency club in the period of 2020-2024 (0.662) is enhanced compared with that in the period of 2013-2019, and the efficiency club stabilizes in the poles, which is the most probable. The possibility of the efficiency club is the largest. It is concluded that the low-carbon development of Hainan tourism should optimize the tourism traffic structure, define the key areas for emission reduction, strengthen regional collaboration, change the development mode, control the scale of hospitality, improve the technical level and promote the construction of new urbanization, so as to build a comprehensive path system for carbon emission reduction in the tourism industry.

Index Terms Entropy weight method, Super-efficiency-SBM model, Hainan tourism industry, Carbon emission efficiency, Spatial and temporal evolution characteristics, Emission reduction path optimization

I. Introduction

With the development of tourism, the impact of tourism on climate and environment has increasingly received widespread attention from the society [1], [2]. The carbon emission problem of tourism has gradually become another hot spot of tourism academic research [3]. Tourism development in Hainan Province has always been famous for its beautiful environment, and tourism is also an important pillar industry in Hainan Province, it is of positive significance to assess the carbon emission efficiency of Hainan tourism and propose optimization solutions for emission reduction paths [4]-[7].

Carbon emission efficiency is essentially the production technology efficiency that incorporates carbon emissions, so scientific and reasonable enhancement of the tourism industry's carbon emission efficiency has become an objective requirement to promote the development of tourism decarbonization [8], [9]. Due to the superimposed effects of the level of economic development, the level of tourism technology and industrial structure, the carbon emission efficiency of Hainan's tourism industry is characterized by significant spatial correlation [10]-[12]. At the same time, the inter-provincial tourism economic spatial correlation is gradually increasing, the spatial pattern of tourism development continues to optimize, the spatial structure of the tourism industry's carbon emission efficiency is also increasingly diversified, dynamic and complex network [13], [14]. Therefore, the emission reduction path optimization program is of great significance for the sustainable development of Hainan tourism, which can be upgraded through industrial structure, technological application innovation, ecological carbon sink expansion and other programs in order to reduce tourism carbon emissions in Hainan Province [15]-[18].

Climate change has become a global environmental issue of common concern, and reducing carbon emissions is an important way to cope with climate change. As an important pillar industry of the national economy, tourism creates economic value and generates a large amount of carbon emissions at the same time. Hainan Province has become a popular tourist destination for both domestic and foreign tourists based on its unique natural and cultural landscapes. However, Hainan has a fragile ecological environment, and carbon emissions from tourism activities pose a potential threat to its ecosystem. Therefore, it is of great practical significance to assess the carbon emission efficiency of Hainan's tourism industry and explore emission reduction paths in order to promote the low-carbon and high-quality development of Hainan's tourism industry. The carbon emission efficiency of Hainan tourism refers to the degree of minimization of CO_2 emissions in the production and service process of Hainan tourism under the given input and output levels of production factors, the essence of which is to emphasize the effective use of resources and minimize the impact on the environment, maximize the pursuit of economic output, and achieve the optimal balance between the environment, the economy and the society. Currently, the research on carbon emission of Hainan tourism mainly focuses on carbon emission measurement, influencing factors and emission reduction strategies, but lacks the research of systematically analyzing the carbon emission efficiency of Hainan tourism from the perspective of spatial and temporal evolution. In addition, most of the existing studies adopt the traditional SBM model, which cannot deal with the slack variables of input and output, resulting in large deviations in the efficiency values. In view of this, based on the concept of “environment-society-economy” symbiosis, this study constructs an evaluation index system for the carbon emission efficiency of Hainan tourism industry, measures the carbon emission of tourism industry by the entropy weight method, evaluates the carbon emission efficiency by using the super-efficiency-SBM model, and analyzes its temporal and spatial evolution characteristics by Markov chain, so as to put forward targeted optimization schemes of emission reduction paths. This study will provide theoretical support for the construction of an international tourism consumption center and a national ecological civilization pilot area in Hainan. The study builds a research mechanism framework based on the theory of “carbon emission reduction in time-space-effectiveness-benefit”, and clarifies the connotation of carbon emission efficiency of Hainan tourism industry and the evaluation index system; secondly, the entropy weight method is used to measure the carbon emission and energy consumption of Hainan tourism industry in 2013-2024; thirdly, the super-efficiency-SBM model is used to evaluate the carbon emission efficiency of Hainan tourism industry, and its temporal and spatial evolution characteristics are analyzed by Markov chain; finally, the optimization scheme of targeted emission reduction paths is proposed. Finally, based on the results of empirical analysis, an optimization scheme for the emission reduction path of Hainan tourism is proposed. The innovations of this study include: overcoming the drawbacks of the traditional SBM model by adopting the super-efficiency-SBM model and improving the efficiency evaluation accuracy; revealing the temporal characteristics of the convergence of carbon emission efficiency clubs in Hainan tourism through Markov chain analysis; and constructing a multi-dimensional emission reduction pathway system of “transportation-lodging-activities”, which provides a precise basis for the implementation of policies for low-carbon development of the tourism industry in Hainan.

II. Data sources and research methodology

II. A. Research mechanisms

Hainan's tourism industry is characterized by rich natural resources, fragile ecological environment, strong seasonality and multi-sectoral collaboration. Relying on a variety of natural and humanistic landscapes in the coastal zone, islands and oceans, Hainan tourism destinations attract a large number of tourists, who enjoy the marine scenery while placing higher demands on the recreational environment. However, the environment of Hainan is fragile, and Hainan tourism activities carried out here may cause irreversible impacts on the marine ecological environment, so it is particularly important to rationally develop Hainan tourism resources, accelerate the realization of green and low-carbon development of Hainan tourism, and protect the marine ecological environment. Carbon emission reduction “time-space-efficiency-benefit” integration theory is an important theoretical basis for the study of carbon emission efficiency of the tourism industry in Hainan, the theory that in the conditions of limited resources, only through the optimization mechanism, the rational allocation of resources, in order to achieve the overall efficiency maximization. According to this theory, the carbon emission efficiency of Hainan tourism refers to the degree of minimization of CO2 emissions in the production and service process of Hainan tourism under a given level of input and output of production factors, the essence of which is to emphasize the effective use of resources and minimization of environmental impacts, and the pursuit of maximizing economic outputs, in order to achieve the optimal balance between the environment, the economy and society. The carbon emission efficiency of Hainan's tourism industry follows the concept of symbiosis between the three systems of “environment-society-economy”, and is an important characterization for assessing the low-carbon development of Hainan's tourism industry. Through the rational allocation of capital, labor, energy and other factors of production in Hainan tourism, it aims to improve the utilization efficiency of tourism resources and reduce carbon emissions, so as to fully realize the economic, social and ecological values of Hainan tourism. The carbon emission efficiency of Hainan tourism interacts with the three systems of environment-society-economy. On the one hand, the improvement of the carbon emission efficiency of Hainan tourism is important for increasing the economic benefits of Hainan tourism, promoting the transformation and upgrading of Hainan tourism, reducing the carbon emission to protect the ecological environment, improving the recreational environment to enhance the experience of tourists and driving the employment of local residents [19], and so on. On the one hand, the improvement of carbon emission efficiency in Hainan tourism is of great significance to increase the economic benefits of Hainan tourism, promote the transformation of Hainan tourism, reduce carbon emissions to protect the ecological environment, improve the recreational environment to enhance the experience of tourists and drive the employment of local residents.

On the other hand, the three systems of economy, environment and society are important for improving the carbon emission efficiency of Hainan tourism. First, the economic benefits are reflected in the provision of financial security for scientific and technological innovation, the promotion of the use of green production technology, reduce resource consumption and waste, and promote the green and low-carbon transformation and upgrading of the Hainan tourism industry. Secondly, the social value is manifested in the fact that by promoting green and low-carbon Hainan tourism products and services, it not only enriches the tourists' experience, but also enhances the vitality of Hainan's tourism economy, promotes energy-saving and emission-reducing tourism products, and protects the ecological environment. Finally, the environmental impact lies in the process of providing tourists with green and low-carbon tourism products and services, which can improve the recreational environment and at the same time mitigate the negative impacts of Hainan tourism activities on the Hainan strip. Therefore, the carbon emission efficiency of Hainan's tourism industry aims to improve economic efficiency, reduce environmental impacts, and enhance social well-being, forming a three-circle cycle of interaction, thus accelerating the green and low-carbon transformation of Hainan's tourism industry. The mechanism framework of carbon emission efficiency of Hainan tourism is shown in Figure 1.

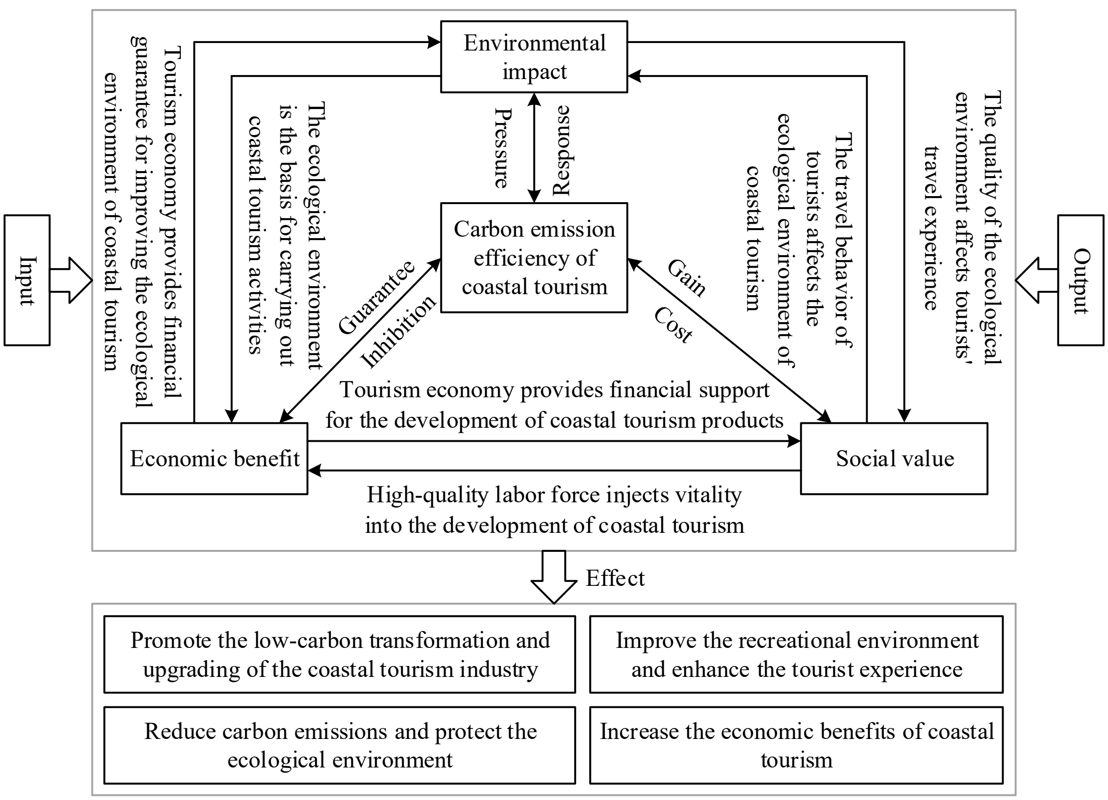

Figure 1: Research Mechanism on Carbon Emission Efficiency of Coastal Tourism

II. B.Indicator system and data sources

II. B. 1) Indicator system

In this paper, capital, resources, labor and energy are used as input indicators, desired outputs are characterized by the total income and total number of visits of Hainan tourism, and non-desired outputs are expressed by the carbon emissions of Hainan tourism.

Since a perfect tourism database has not been established yet, the total carbon emissions and energy consumption of tourism in Hainan are measured by the entropy value method. In the indicator system, since the data related to coastal tourism cannot be obtained directly, the total income of tourism, energy consumption of tourism and total carbon emission are obtained indirectly by multiplying the total income of tourism, energy consumption and total carbon emission in the region by the ratio of the gross domestic product (GDP) of the region to the GDP, the resource inputs are obtained by summing up the number of star-rated hotels, travel agencies and A-grade scenic spots in the coastal cities in each region, and the total number of tourism trips is obtained by summing up the total number of tourism trips in the coastal cities in each region. Total tourism trips are expressed by adding up the total number of tourism trips in coastal cities in each region.

II. B. 2) Data sources

The research period of this paper is 2013 -2024, with Hainan Province as the research object, the data related to energy consumption of each sector, digital economy and regional innovation capacity of Hainan Province are all from Hainan Provincial Statistical Yearbook and the official website of the National Bureau of Statistics, the tourism revenue and the number of tourists received per year are from the official website of the Department of Tourism, Culture, Radio, Television and Sports of Hainan Province, of which the tourism revenue has been converted into the 2013-based period of the Constant price, this paper uses interpolation to fill in some of the missing data values.

II. C.Research methodology

II. C. 1) super-SBM modeling

In order to better compensate for the drawbacks of the traditional SBM model that cannot deal with the slack variables of inputs and outputs, and cannot further compare the effective units, thus leading to a large deviation of the efficiency value, this paper adopts the super-SBM model based on non-expected outputs to measure the carbon emission efficiency of Hainan's tourism industry [20]. This model overcomes the above drawbacks, not only considering the slack variables, but also realizing the further comparison of the effective decision-making units, which in turn enhances the accuracy of the calculation results and improves the precision of efficiency evaluation. The calculation formula is as follows:

$$\min \delta = \frac{\frac{1}{m}\sum_{i=1}^{m}\frac{\overline{x}_i}{x_{ik}}}{\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{\overline{y}_r^g}{y_{nk}^g}+\sum_{r=1}^{s_2}\frac{\overline{y}_l^b}{y_{lk}^b}\right)} \tag{1}$$

$$s.t.\begin{cases} \overline{x} \geq \sum_{j=1,\neq 0}^{n}\lambda_j x_i \\ \overline{y}^g \leq \sum_{j=1,\neq 0}^{n}\lambda_j y_j^g \\ \overline{y}^b \geq \sum_{j=1,\neq 0}^{n}\lambda_j y_j^b \\ \overline{x} \geq x_k, \overline{y}^g \leq y_k^g, \overline{y}^b \geq y_k^b, \overline{y}^g \geq 0, \overline{y}^b \geq 0, \lambda \geq 0 \end{cases} \tag{2}$$

where δ is the carbon emission efficiency of Hainan's tourism industry; λ is the weight vector; x_{ij}, y_{ij}^g and y_{ij}^b denote the quantities of inputs, desired outputs, and non-desired outputs for the decision-making unit; x_i, y_r^g and $\overline{y}_l^b$ are slack variables for inputs, desired outputs and non-desired outputs, respectively; m, s_1 and s_2 denote the number of indicators for inputs, desired outputs and non-desired outputs.

II. C. 2) Entropy method

The entropy value method can objectively reveal the degree of influence of each indicator on the high-quality development of agriculture, and take into account the comparability of indicators between different years [21]. The steps are as follows:

1) Calculate the entropy value of the j th indicator:

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} P_{ij} \ln P_{ij} \tag{3}$$

Among them:

$$P_{ij} = X_{ij}^{'} / \sum_{i=1}^{n} X_{ij} \tag{4}$$

where, e_j is the entropy value of the j th indicator, P_{ij} is the share of the j th indicator in the i th year, $X_{ij}^{'}$ is the value of the j th indicator in the i th year after normalization, and n is the number of years.

2) Calculate the weight of the j th indicator:

$$W_j = \frac{1-e_j}{\sum_{j=1}^{m}(1-e_j)} \tag{5}$$

where, W_j is the weight of the j th indicator and m is the number of indicators.

3) Calculate the level of high-quality development of agriculture:

$$Y_i = \sum_{j=1}^{m} W_j X_{ij} \tag{6}$$

where, Y_i is the level of high-quality agricultural development in year i .

II. C. 3) Methodologies for measuring carbon emissions from tourism

The domestic tourism industry has not yet compiled data on carbon dioxide emissions and energy consumption, nor has it established a specialized tourism satellite carbon account database. Therefore, with reference to the existing studies, the carbon emissions of the tourism industry are obtained by measuring the carbon emissions of each market segment through the “bottom-up” method [22]. The specific methods are as follows:

$$E^t = \sum_{i=1}^{3} E_i^t = E_1^t + E_2^t + E_3^t \tag{7}$$

where, E^t denotes the carbon emissions and energy consumption of the tourism industry in year t , and E_i^t denotes the carbon emissions and energy consumption of i segments of the tourism industry in year t ; E_1^t, E_2^t, E_3^t denote the carbon dioxide emissions and energy consumption of tourism transportation, tourism accommodation, and tourism activities in year t , respectively:

$$E_1^t = \sum_{i=1}^{4} Q_i^t \cdot f_i \cdot a_i \tag{8}$$

where, Q_i^t is the passenger turnover of i transportation modes in year t , and the transportation modes are highway, civil aviation, railroad, and waterway; f_i is the proportion of tourist in the passenger flow of i transportation modes, and the proportions of highway, civil aviation, railroad, and waterway are 4.0%, 65.6%, 32.4%, and 10.8%, respectively, and α_i is the carbon dioxide emission factor and energy consumption factor of i transportation modes, and the carbon dioxide emission factors of road, civil aviation, railroad, and water transportation are 137gCO^2/p·km, 140gCO^2/p·km, 25gCO^2/p·km, and 119gCOCO^2/p·km, and the energy consumption factors are 1-8MJ/p ·km, 2MJ/p·km, 1MJp·km, and 0.9MJ/p·km, respectively:

$$E_2^t = Q^t \cdot G^t \cdot \beta \tag{9}$$

where, Q^t is the number of guest room beds in star-rated hotels in year t, G^t is the average room occupancy rate of star-rated hotels in year t, and β is the carbon dioxide emission coefficient and the emission coefficient of energy consumption per bed per night, which are 2.465gCO^2/p·d and 158MJ/p·d, respectively:

$$E_3^t = \sum_{k=1}^{5} P_k^t \cdot \lambda_k \tag{10}$$

where, P_k^t is the number of people participating in k types of tourism activities in t years, tourism activities are sightseeing tourism, business tourism, leisure and vacation tourism, visiting friends and relatives tourism, other types of activities tourism, λ_k represents the carbon dioxide emission factor of participating in k types of tourism activities (420gCO^2/tourist, 789gCO^2/tourist, 1674gCO^2/tourist, 597gCO^2/tourist, 173gCO^2/tourist), and energy consumption factor (8.9MJ/tourist, 27.0MJ/tourist, 17MJ/tourist, 18MJ/tourist, 3,6MJ/tourist).

III. Analysis of results

III. A. Analysis of the overall tourism carbon emission change trend in Hainan

Carbon emissions from the overall tourism industry in Hainan Province from 2013 to 2024 are shown in Figure 2.From 2013 to 2023, the carbon emissions from the overall tourism industry in Hainan Province increased from 2,326,669,000t to 8,364,280,000t, an increase of 6,037,590,000t, or a 3.595-fold increase. By 2024, the overall tourism carbon emissions in Hainan Province will decrease to 3,538,260,000 tons, and the overall tourism carbon emissions in Hainan Province will decrease by 57.70% in 2024 compared with 2023.

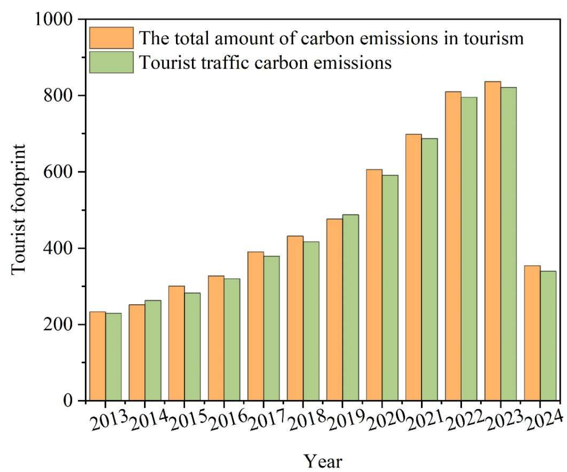

Figure 2: The overall tourism industry of hainan province is changing

The changing trend of overall carbon emissions from tourism accommodation and carbon emissions from tourism activities in Hainan Province is shown in Figure 3.The changing trend of overall carbon emissions from tourism accommodation in Hainan Province from 2013 to 2024 is consistent with the changing trend of carbon emissions from tourism, and the changing trend of overall carbon emissions from tourism activities and carbon emissions from tourism accommodation in Hainan Province are both roughly consistent with the changing trend of carbon emissions from tourism.From 2013 to 2023, the Carbon emissions from accommodation in Hainan Province increased from 70t to 287.292t, an increase of 217.292t, an increase of 4.104 times.

From 2013 to 2023, carbon emissions from tourism activities increased from 12.32 million tons to 49.69 million tons, with an average annual growth rate of 37.37%, and only slightly decreased in 2024.

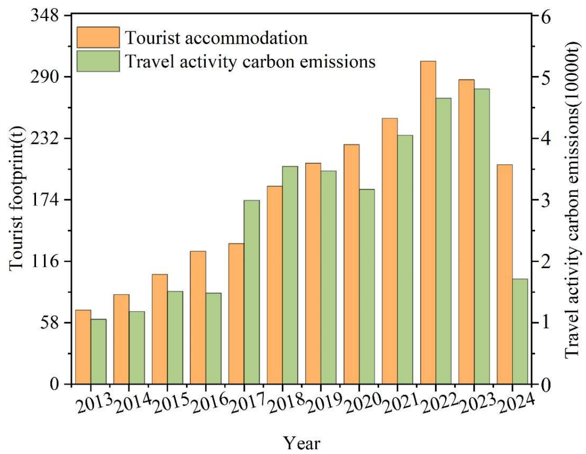

Figure 3: Carbon emissions and carbon emissions from tourist accommodation

The carbon emission intensity of the overall tourism industry in Hainan Province from 2013 to 2024 shows a decreasing trend in fluctuation as shown in Figure 4. The carbon emission intensity of the overall tourism industry in Hainan Province decreases from 2.064t/million yuan in 2013 to 0.427t/million yuan in 2024, which is a decrease of about 79.31%, with an average annual decrease rate of 7.93%. The changes in the carbon emission intensity of the overall tourism industry in Hainan Province can be specifically divided into the following three stages: 2013-2018 is the first stage, in which the carbon emission intensity of the tourism industry shows a sharp downward trend.

2018-2022 is the second stage, the carbon emission intensity of the tourism industry shows a slow decline in fluctuation, from 1.006t/million yuan in 2014 to 0.789t/million yuan in 2022.2022-2024 is the third stage, the carbon emission intensity of the tourism industry shows a rapid decline, from 0.729t/million yuan in 2022 to 2024 in 2022 to 0.427t/million yuan in 2024, with an annual decline rate of 41.43%. It can be seen that with the improvement of tourism low-carbon technology and optimization of energy structure Hainan Province, the overall tourism industry energy saving and emission reduction results gradually appeared, and the level of low-carbon development continues to improve.

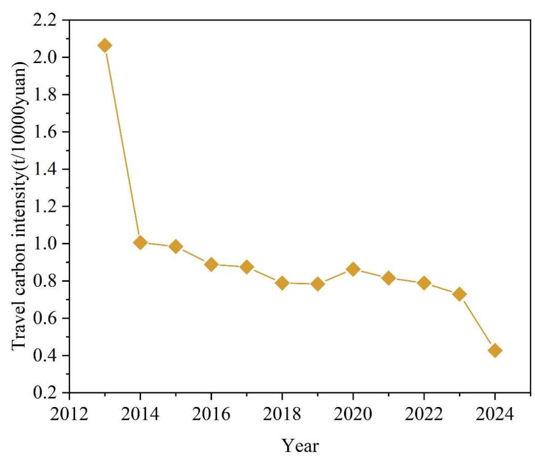

Figure 4: Overall tourism industry carbon intensity change situation

III. B. Temporal Characterization of Convergence in Tourism Carbon Emission Efficiency in Hainan Regions

Based on the super-efficiency-SBM model, the carbon emission efficiency of the tourism industry in Hainan Province was calculated from 2013 to 2024, and the average values of the carbon emission efficiency of the tourism industry in the eastern, central and western parts of Hainan Province and the tourism industry in Hainan Province were calculated based on the division of eastern, central and western parts of Hainan Province by the National Development and Reform Commission (NDRC), as shown in Fig. 5.

(1) The average value of efficiency in the eastern part of Hainan Province fluctuates around 0.55~0.65, with little ups and downs and a slow decline in the shape of “W”, but the overall level is higher than that in the central and

western parts of Hainan Province. It is least efficient in 2020 at 0.5399 and most efficient in 2019 at 0.66. This is also consistent with the reality that the eastern part of Hainan Province has always been a tourist hotspot, with more mature tourism development and a sound environmental regulatory system, while in recent years the tourism competition has been fierce, and the increase in the economic benefits of tourism in the eastern part of Hainan Province has slowed down a little bit, making it more difficult to prevent and control carbon emissions, and thus the efficiency of the tourism industry in terms of carbon emissions has declined.

(2) The average value of efficiency in the central region of Hainan Province shows a similar development trend to that of Hainan Province, with an average value of 0.5425, which is lower than the average value of the central and eastern parts of the country, with large up and down ups and downs, hitting the bottom in 2017 and peaking in 2019, indicating that the central region of Hainan Province has the lowest overall level of carbon emission efficiency in the tourism industry and is in a precarious state of development.

(3) The average value of efficiency in the western region of Hainan Province is 0.5677, with the lowest efficiency in 2020 and the highest efficiency in 2018, and the overall fluctuating upward trend, mainly due to the fact that the western region of Hainan Province has attracted a large number of tourists with its pristine natural scenery in recent years, and the rapid growth of the economic benefits of tourism, and secondly, the sparsely populated western region of Hainan Province, and the strict implementation of the control of carbon emissions, so the tourism industry's carbon emission efficiency of the tourism industry is relatively high.

(4) The average efficiency of Hainan Province reached 0.5817, with two "troughs" in 2017 and 2020, and two "peaks" in 2018 and 2022, showing a "roller coaster" fluctuation of alternating troughs and peaks, which is related to the continuous adjustment of tourism and environmental policies in Hainan Province in recent years, the deepening of supply-side reform of the tourism industry, and the unstable shift period from quantity to quality of the tourism industry.

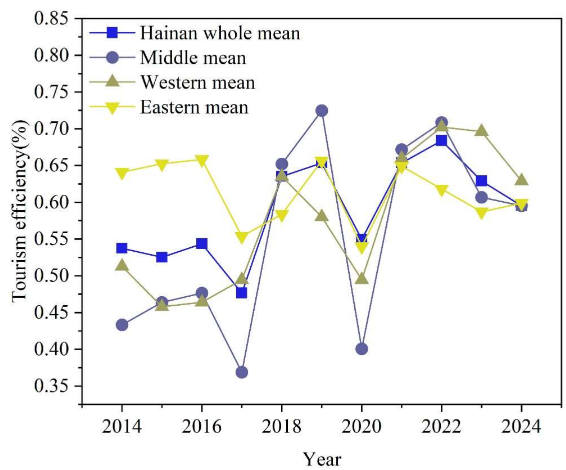

Figure 5: The efficiency of carbon emissions in hainan tourism industry

In order to further examine the medium- and long-term temporal characteristics of the convergence of tourism carbon emission efficiency clubs in Hainan Province, this paper divides the study period into two study periods, 2013-2019 and 2020-2024, and calculates the transfer probability of the tourism carbon emission efficiency in Hainan Province in each time period, respectively, based on the temporal Markov chain The matrix is shown in Table 1.

The values of the main diagonal in the Markov chain transfer probability matrix of tourism carbon emission efficiency in Hainan Province in 2013-2019 are significantly higher than the values on both sides, which implies that the carbon emission efficiency of the tourism industry in 2013-2019 shows a significant club convergence distribution. Where the main diagonal values indicate the probability that the efficiency stays in the same rank club convergence, and the off-diagonal values indicate the probability that the efficiency shifts between different rank clubs. First, in the probability of convergence of clubs of the same rank, the likelihood of convergence is highest for less efficient clubs, followed by highly efficient clubs (68.2%), less efficient clubs (64.5%) and more efficient clubs (47.1%).

Secondly, among the transfer probabilities of different levels of clubs, the probability of transferring from higher efficiency to lower efficiency is the largest at 33.4%, while the probability of transferring from higher efficiency to lower efficiency is the smallest at 0.1%, which shows that there is a higher probability of transferring from clubs of adjacent efficiency levels, while the probability of transferring efficiencies across levels of clubs is small. In the 2020-2024 probability matrix of carbon emission efficiency transfer in the tourism industry in Hainan Province, the probability value on the same main diagonal is significantly higher than that on the non-diagonal, and the club convergence index is 0.662, indicating that the convergence effect in 2020-2024 is higher than that in 2013-2019 There is an increase. First, among the probabilities of convergence of clubs of the same rank, among which the probability of stabilizing in the inefficient clubs is the largest, followed by the efficient clubs (78.9%), the less efficient clubs (72.8%) and the more efficient clubs (33.4%), it is evident that stabilizing in the clubs of the two extremes of the efficiency class is the most likely to be stabilized at least at 78.9%, while stabilizing in the clubs of the middle class is less likely to be stabilized, at least 33.4%. Secondly, among the transfer probabilities of different rank clubs, the likelihood of transferring from more efficient to less efficient is the largest at 38.6%, while the likelihood of transferring from less efficient to more efficient clubs is the smallest at 0.1%, implying that downward transfers of efficiency are more likely than upward transfers, and that transfers to clubs of neighboring ranks are more likely to occur.

Table 1: Markov chain transfer probability matrix

	2013-2019				2020-2024			
	A	B	C	D	A	B	C	D
Low efficiency	0.645	0.286	0.046	0.047	0.804	0.163	0.001	0.045
Medium-low efficiency	0.063	0.816	0.063	0.072	0.086	0.728	0.168	0.032
Medium-high efficiency	0.001	0.337	0.471	0.204	0.045	0.386	0.334	0.255
High efficiency	0.037	0.198	0.098	0.682	0.030	0.112	0.060	0.789

III. C. Optimization of Emission Reduction Path for Hainan Tourism

According to the contents and conclusions of the research in this paper, the following optimization schemes are mainly obtained:

(1) Build low-carbon tourism transportation and optimize the carbon emission structure of tourism. From the measurement results of tourism carbon emissions, it can be seen that tourism carbon emissions are composed of three parts: tourism transportation carbon emissions, tourism accommodation carbon emissions and tourism activities carbon emissions, among which, tourism transportation carbon emissions account for the highest proportion of tourism carbon emissions and are the main source of tourism carbon emissions, so the control of tourism transportation carbon emissions is a key link in the carbon emission reduction of the tourism industry.

(2) Define the key areas for emission reduction in the tourism industry and narrow the gap of carbon emission in the tourism industry. Defining the key areas for emission reduction in the tourism industry and narrowing the gap of carbon emissions in various regions and sectors of the tourism industry is an important path to realize low-carbon and high-quality development of the tourism industry. From the viewpoint of the spatial pattern of carbon emissions and intensity of the tourism industry in Hainan Province, at present, the carbon emissions and intensity of the tourism industry in the southern and northern regions of Hainan Province are the highest, and the level of its economic development in the tourism industry is also high.

(3) Based on the fact of differences, strengthen inter-regional collaboration. Strengthening regional collaboration and giving full play to their respective advantages is an important way to effectively promote the implementation of tourism emission reduction policies.

(4) Transform the mode of economic development and promote energy conservation and emission reduction. At present, the carbon emission intensity of the tourism industry in Hainan Province is still at a relatively high level, indicating that Hainan Province is still sacrificing the environment and over-consuming resources and energy in exchange for economic development of the tourism industry, and fails to realize the synergistic development of the tourism industry and the environment.

(5) Reasonably control the scale of tourism reception and publicize the concept of low-carbon tourism. In recent years, with the great improvement of people's living standards, people's demand for tourism is rapidly increasing, Hainan Province, as China's major tourism province, the expansion of the scale of tourism reception to bring economic growth in the tourism industry at the same time “contribute” considerable carbon emissions.

(6) Improve the technical level and reduce the energy intensity of tourism. Due to technical problems and cost considerations, the energy utilization rate of various sectors of the tourism industry in the cities and counties of Hainan Province will not be substantially increased.

(7) Promote new urbanization and achieve sustainable development. As the level of urbanization continues to increase, the transfer of a large number of people from rural to urban areas will place demands on the expansion and improvement of infrastructure, which will prolong the stay of tourists in cities.

IV. Conclusion

Carbon emissions from tourism in Hainan Province show obvious spatial and temporal characteristics. In the time dimension, from 2013 to 2023, the carbon emission of tourism in Hainan Province increased from 2,326,690,000 tons to 8,364,280,000 tons, an increase of 3.595 times, and decreased to 3,538,260,000 tons in 2024, a year-on-year decrease of 57.70%. The carbon emission intensity of the tourism industry as a whole shows a downward trend, from 2.064 tons per million yuan in 2013 to 0.427 tons per million yuan in 2024, a decrease of 79.31%. In the spatial dimension, the carbon emission efficiency of the tourism industry in the eastern part of Hainan Province is higher than that in the central and western parts of the country, but it has been declining slowly in recent years in the shape of "W"; the average value of the efficiency in the central part of the country is the lowest (0.5425), with large ups and downs; the efficiency in the western part of the country has been fluctuating upward, with an average value of 0.5677. Markov chain analysis shows that the tourism industry in Hainan Province in the period of 2020-2024 has the following carbon emission efficiency clubs Convergence effect (0.662) is enhanced compared with 2013-2019, and the possibility of downward transfer of efficiency is greater than upward transfer.

Based on the results of the study, the low-carbon development path of Hainan tourism can be optimized in seven aspects: building low-carbon tourism transportation, optimizing the carbon emission structure; defining the southern and northern regions as the key areas for emission reduction, narrowing the regional carbon emission gap; strengthening inter-regional collaboration based on the fact of differences; transforming the mode of economic development, promoting energy conservation and emission reduction; rationally controlling the scale of tourism reception, promoting the concept of low-carbon tourism; improving the level of technology, reducing the energy intensity of the tourism industry; and promoting the development of low-carbon tourism. Reduce the energy intensity of tourism; Promote the construction of new urbanization to achieve sustainable development. Through these measures, a complete carbon emission reduction pathway system will be constructed for Hainan's tourism industry, promoting the coordinated development of Hainan's tourism industry and ecological environment, and helping Hainan to build an international tourism consumption center and a national ecological civilization pilot area.

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References

[1] Zhao, J., & Li, S. M. (2018). The impact of tourism development on the environment in China. Acta Scientifica Malaysia, 2(1), 1-4.

[2] Gazta, K. (2018). Environmental impact of tourism. AGU International Journal of Professional Studies & Research, 6(6), 7-17.

[3] Ren, T., Can, M., Paramati, S. R., Fang, J., & Wu, W. (2019). The impact of tourism quality on economic development and environment: Evidence from Mediterranean countries. Sustainability, 11(8), 2296.

[4] Zhang, S., & Ju, H. (2021). The regional differences and influencing factors of tourism development on Hainan Island, China. Plos one, 16(10), e0258407

[5] Lin, Q., She, S., Wang, Q., & Gong, J. (2020). Factors affecting the cooperation in regional tourism and its countermeasures: a case from North Hainan, China. Current Issues in Tourism, 23(7), 826-835.

[6] Zhang, P., Yu, H., Shen, M., & Guo, W. (2022). Evaluation of tourism development efficiency and spatial spillover effect based on EBM model: The case of Hainan Island, China. International Journal of Environmental Research and Public Health, 19(7), 3755.

[7] Kun, X., Ullah, W., Dejun, L., & Ziyun, W. (2025). Exploring the spatial patterns and influencing factors of rural tourism development in Hainan Province of China. Scientific Reports, 15(1), 1602.

[8] Sun, W., & Huang, C. (2020). How does urbanization affect carbon emission efficiency? Evidence from China. Journal of Cleaner Production, 272, 122828.

[9] Yu, Y., & Zhang, N. (2021). Low-carbon city pilot and carbon emission efficiency: Quasi-experimental evidence from China. Energy Economics, 96, 105125.

[10] Gao, P., Yue, S., & Chen, H. (2021). Carbon emission efficiency of China's industry sectors: From the perspective of embodied carbon emissions. Journal of cleaner production, 283, 124655.

[11] Wang, G., Deng, X., Wang, J., Zhang, F., & Liang, S. (2019). Carbon emission efficiency in China: A spatial panel data analysis. China Economic Review, 56, 101313.

[12] Dong, F., Zhu, J., Li, Y., Chen, Y., Gao, Y., Hu, M., ... & Sun, J. (2022). How green technology innovation affects carbon emission efficiency: evidence from developed countries proposing carbon neutrality targets. Environmental Science and Pollution Research, 29(24), 35780-35799.

[13] Wang, D. G., Niu, Y., & Qian, J. (2018). Evolution and optimization of China's urban tourism spatial structure: A high speed rail perspective. Tourism Management, 64, 218-232.

[14] Lu, F., Qin, W., & Wang, Y. X. (2021). Research on Spatial Pattern Dynamic Evolution Algorithm and Optimization Model Construction and Driving Mechanism of Provincial Tourism Eco‐Efficiency in China under the Background of Cloud Computing. Scientific Programming, 2021(1), 1951264.

[15] Wang, Y., Yang, H., & Sun, R. (2020). Effectiveness of China's provincial industrial carbon emission reduction and optimization of carbon emission reduction paths in “lagging regions”: efficiency-cost analysis. Journal of Environmental Management, 275, 111221.

[16] Wei, R., & Liu, C. (2020). Research on carbon emission reduction in road freight transportation sector based on regulation-compliant route optimization model and case study. Sustainable Computing: Informatics and Systems, 28, 100408.

[17] Sun, Y. Y., Lin, P. C., & Higham, J. (2020). Managing tourism emissions through optimizing the tourism demand mix: Concept and analysis. Tourism management, 81, 104161.

[18] Yu, Y., Mao, X., & Sui, S. (2025). Evaluation of Carbon Emission Efficiency and Optimization of Optimal Emission Reduction Path in Hainan Tourism Based on Data Envelopment Calculation Analysis. J. COMBIN. MATH. COMBIN. COMPUT, 127, 7001-7017.

[19] Luman Zheng. (2024). Exploring the Impact of Hainan Tourism Development in the New Social Media Environment -- Taking Douyin Short Video Platform as an Example. Research and Commentary on Humanities and Arts,2(12).

[20] Peide Liu,Huizhi Sun & Hongxue Xu. (2025). Performance evaluation of Chinese and foreign property insurance companies considering negative data: Based on the dynamic two-stage IBP-SBM model. Socio-Economic Planning Sciences,98,102169-102169.

[21] Yinhong Yao,Zhuoqi Feng & Xueyong Liu. (2025). Heterogeneous information transmission between climate policy uncertainty and Chinese new energy markets: A quantile-on-quantile transfer entropy method. International Review of Financial Analysis,103,104175-104175.

[22] Chao Bi & Jingjing Zeng. (2019). Nonlinear and Spatial Effects of Tourism on Carbon Emissions in China: A Spatial Econometric Approach. International Journal of Environmental Research and Public Health,16(18),3353-3353.