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Research Progress and Prospect of Tourism Carbon Emissions and Its Uncertainty Analysis Under the Goal of Low-Carbon Scenic Spots

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Abstract: Under the dual carbon goal, China Certified Emissions Reductions (CCER) and the national carbon market have become important means of emission reduction and control. The tourism industry is a strategic pillar industry of China's national economy, and scenic spots are the main sites of tourism activities. Research on carbon emissions in scenic spots is of great significance for the construction of low-carbon scenic spots and the realization of the dual carbon goal. In this paper, the research on carbon emissions in tourism is reviewed, the current research progress is discussed, and further prospects are made. The research on tourism carbon emissions in China has a good foundation and achieved certain results. However, there are few studies on micro-scales such as scenic spots. The statistical data caliber and measurement methods of carbon emissions are not uniform, and there is a general lack of uncertainty analysis. Future research should focus on building a multi-spatial dimension research system, unifying the statistical caliber and measurement methods of carbon emission data, increasing uncertainty analysis, and ensuring the robustness of research results.

Keywords: Low-carbon scenic spot; Carbon emissions; Uncertainty analysis

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1. Introduction

Under the background of global warming and increasingly prominent ecological environment problems, the impact of tourism, as the pillar industry of the tertiary industry, on the environment has attracted the attention of scholars, government departments, and relevant organizations at home and abroad. In the 2014 China-US Joint Statement on Climate Change, China proposed to achieve "carbon peak" in 2030 and "carbon neutrality" in 2060. In order to achieve the dual carbon goal, every industry in China is facing new challenges of energy conservation and emission reduction. At the 20th National Congress of the Communist Party of China in 2022, propositions to promote green development, build a beautiful China, and actively and steadily promote carbon peak and carbon neutralization were made. In order to coordinate the two strategic objectives of tourism development and both energy conservation and emission reduction, there is a need to vigorously promote low-carbon transformation and development in tourism [1].

Carbon emissions trading is an important means of emission control. In July 2021, the national carbon market started trading. By the end of 2022, the cumulative trading volume of carbon emission allowance (CEA) in the national carbon market was 2.233 tons, with a cumulative trading volume of 10.121 billion yuan [2]. The range of the national carbon market trading price is 44–60 yuan per ton, and carbon emission rights have become the fifth asset of enterprises carbon assets. The emission reduction potential of tourist attractions is huge and promising in the carbon market. As a market unit, scenic spots have a large number of carbon sink resources, such as wetlands, forests, and lakes, while bringing a large amount of carbon emissions from tourism activities. The potential for emission reduction is huge. They should actively participate in the carbon trading market and play a catalytic role in achieving national and local carbon neutrality goals. Carbon market transactions require high data quality, as data quality is the lifeline of the national carbon market. Therefore, it is of practical significance to carry out research on carbon emissions in tourist attractions.

2. Research status of carbon emissions in tourist attractions

At present, there are few low-carbon policies related to tourism. The China Environmental Protection Federation and the China Tourist Attractions Association selected 19 National Low-Carbon Tourism Demonstration Zones in 2011, and the Sustainable Development Guide for Tourist Attractions approved by the Ministry of Culture and Tourism in 2021 only provides directional guidance for low-carbon construction and sustainable development of scenic spots. With the advent of the era of mass tourism, there will be significant carbon emissions from tourism-related activities. Scenic spots are the main sites of tourism activities, and the construction of low-carbon scenic spots is of great significance. The construction of low-carbon scenic spots requires low-carbon evaluation standards and relevant emission reduction measures. Therefore, calculating the carbon emissions of scenic spots, finding key carbon emission factors, and exploring targeted emission reduction paths will help promote the construction of low-carbon scenic spots in China.

Greenhouse gases are considered to be one of the important culprits of global warming, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6), among which CO_2 accounts for as high as 75.5 % [3]. Most scholars at home and abroad use CO_2 as the research subject to measure carbon emissions. At present, there are many studies on tourism carbon emissions. From the research scale, the focus mainly is on the estimation of tourism carbon emissions at the global scale [4], national scale [5-7], and provincial scale [8,9]. There are relatively few estimates of carbon emissions at micro-scales such as tourist attractions. From the perspective of research subjects, the focus is mainly on carbon emissions from tourism transportation [10,11], carbon emissions from tourists' consumption behavior [12,13], and low-carbon management of tourism enterprises [14], while there are relatively few studies focusing on tourist attractions.

2.1. Calculation method

The calculation method is the keypoint and focus of tourism carbon emissions research. Scholars mainly use two methods, namely the top-down method based on input-output theory and the bottom-up method based on life cycle theory. The main difference between the two is the data source. Top-down data are mainly derived from statistical yearbooks, tourism satellite accounts, and other statistical data, which are used for comparative research on tourism carbon emissions and carbon tax formulation at a larger spatial scale. Bottom-up data, on the other hand, are mainly derived from the measurement data of tourism industry and tourists, which are used to study the impact factors of tourism carbon emissions at a small spatial scale.

2.1.1. Top-down method

According to literature research, although the top-down method uses second-hand data, the statistical data selected by different scholars are different. Some scholars begin from tourism economic indicators to calculate the number of tourists, the per capita cost of tourists, the energy consumption of tourism economy, and its emission coefficient, so as to obtain the tourism carbon emissions [15,16]. Other scholars begin from the tourism energy consumption index and use the ratio of the added value of a certain industry to the total added value of the corresponding industry to obtain the tourism consumption stripping coefficient, and then calculate the various types of energy consumed by the corresponding industry, the tourism consumption stripping coefficient, the corresponding energy standard coal conversion coefficient, the sum of the product of CO_2 emissions of standard coal, and the carbon emissions of the tourism industry. The advantage of this method is that it can directly use government statistical data; thus, it is convenient and fast, simplifies the research process, and is suitable for national and provincial spatial scale research. However, its shortcomings are also evident. First, due to the different selection of statistical data, it is difficult to compare the research in different regions horizontally, and the research results in the same region will also have a huge gap. Secondly, in view of the deep and extensive integration of tourism with other industries, separating and recognizing the energy consumption science related to tourism are the difficulties faced with this method.

2.1.2. Bottom-up method

According to literature research, the bottom-up rule is calculated by scholars according to the actual carbon emission sources of the research object, and the total carbon emission is then estimated. The calculation model of carbon emissions from different carbon sources is relatively uniform, that is, the product of carbon source activity data and carbon emission factors. The Intergovernmental Panel on Climate Change (IPCC) assumes that the carbon emission factor is fixed, and this practice is continued by scholars. Different scholars use different carbon emission factors. Some scholars selected energy (including mobile source fuel and electricity) and waste (including wastewater, solid waste, and manure) as carbon emission factors [13,17]. Some scholars selected tourism activities, such as eating, living, traveling, shopping, entertainment, *etc*., as carbon emission sources. Some scholars subdivided different traffic vehicles (including sightseeing vehicles, private cars, and working vehicles) and calculated the traffic carbon emissions of scenic spots by combining the number of passengers [18]. Some scholars selected transportation, scenic area management (including office, tourist facilities, and public facilities) and solid waste as carbon emission sources [19]. The advantage of this method is the accuracy of data, with fine analysis, and it is suitable for small spatial scale carbon emission research. On the other hand, the disadvantage is the complex and time-consuming data acquisition process, with many uncertainties.

The carbon emission coefficient is applicable to both the bottom-up method and the top-down method. For example, some scholars begin with tourism energy consumption, obtain the gross domestic product (GDP) energy consumption and various energy consumption of the research object through the statistical bulletin of the county where the research object is located, and then multiply the various energy carbon emission coefficients to obtain the total carbon emission of the research object [20]. For tourist attractions, their spatial scales are relatively small; thus, the bottom-up approach is more applicable.

2.2. Carbon emission coefficient of tourist attractions

Carbon emission coefficient refers to carbon dioxide emission coefficient, which is the key value in the calculation process. However, the carbon emission sources of different tourist attractions vary, along with the carbon emission factors. The carbon emission coefficient in common tourism carbon emission research mainly includes traffic carbon emission coefficient, power carbon emission coefficient, water supply carbon emission coefficient, waste carbon emission coefficient, and so on.

2.2.1. Intergovernmental Panel on Climate Change recommended calculation method

The calculation of carbon emission coefficient has not been uniformed across the many studies conducted. However, the calculation method most used is the one recommended by the IPCC. The 2006 IPCC

Guidelines for National Greenhouse Gas Inventories 2019 Revision covers greenhouse gases produced by the energy industry, agriculture, and waste. The IPCC recommended calculation method has been used in many studies [17,19,21,22]. The specific formula is as follows:

$$C = OC \times V$$

where C is the carbon dioxide emission coefficient of a certain type, OC is the original carbon dioxide emission coefficient recommended by IPCC 2006 (2019 revision), and V is the recommended calorific value of this type of energy in China.

2.2.2. Traffic carbon emission coefficient

Traffic carbon emissions are mainly caused by energy. Due to the questionable global or local applicability of the carbon emission coefficient obtained by the IPCC recommended calculation method [1], some scholars have adopted the equivalent standard coal coefficient method [19] to calculate the traffic carbon emission coefficient. The specific formula is as follows:

$$D = E \times I_c \times O_c \times R$$

where D is the carbon dioxide emission coefficient of a certain type of energy, E is the low calorific value of this type of energy, I_c is the carbon content per unit calorific value of this type of energy, O_c is the carbon oxidation rate of this type of energy, and R is the relative atomic mass ratio of carbon dioxide to carbon, in which the general value is 44/12. Among them, the low calorific value of energy, the carbon content per unit calorific value of energy, and the carbon oxidation rate of energy can be obtained in the General Principles for Comprehensive Energy Consumption Calculation and China Greenhouse Gas Emission Accounting Methods and Reporting Guidelines.

2.2.3. Electricity carbon emission coefficient

In order to accurately and conveniently develop Clean Development Mechanism (CDM) projects in China's key emission reduction areas in line with CDM rules and China's greenhouse gas voluntary emission reduction projects (CCER projects), the Department of Climate Change of the Ministry of Ecology and Environment of the People's Republic of China publishes the China Low-Carbon Technology Fossil Fuel Grid-Connected Voluntary Emission Reduction Project Regional Grid Baseline Emission Factors on a yearly basis. The national grid belongs to indirect carbon emissions. For tourist attractions, scholars generally directly refer to the power carbon emission coefficient in the document [17,19] for convenience of research and then multiply it with electricity consumption to obtain the power carbon emissions of the power grid. As for the direct carbon emissions caused by local power generation, it should be calculated by the power generation structure (thermal power generation, hydropower generation, wind power generation, photovoltaic power generation, *etc*.), and the carbon emissions of thermal power generation should be converted according to the emission factors of fuel. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories 2019 Revision does not provide emission factors for power generation; instead, it only provides emission factors for fuels used for power generation and greenhouse gas estimation methods for water injection in reservoir area.

2.2.4. Waste carbon emission coefficient

In the study of tourism carbon emissions, only solid waste is considered as "waste." Waste treatment in China includes landfill, composting, and incineration. The carbon emission coefficient of solid waste is obtained by multiplying the amount of solid waste, unit energy consumption of waste treatment, standard coal conversion coefficient of electric energy, and standard coal coefficient [21].

Most tourism activities take place in major tourist attractions and have become an important area in low-carbon tourism research. The study of carbon emissions in scenic spots is an important part of low-carbon tourism. It can be seen from the above that the research method of carbon emissions in scenic spots has matured, that is, the bottom-up method is used to calculate the product of carbon source activity data and carbon emission factors, and the carbon emissions of scenic spots are then obtained. However, there are great differences in carbon source activity data between tourist attractions, carbon emission factors are complex and diverse, and there are many uncertainties that affect the accuracy of carbon emissions research results. In order to calculate the carbon emissions of scenic spots more accurately and clarify the carbon assets of scenic spots, it is necessary to improve the accuracy and stability of carbon emissions research results and identify the key factors of carbon emissions, so as to formulate more targeted emission reduction measures.

3. Uncertainty analysis

In the actual practice of carbon emission research in tourist attractions, due to conceptual errors such as the unrecognized emission mechanism or the non-existence of measurement methods, there are model errors such as simplification of calculation models and data errors such as limited data sample size, measurement errors, and classification errors, which directly affect the calculation and analysis of carbon emissions. Uncertainty analysis is needed to provide accurate information for emission reduction decisions. It includes quantitative uncertainty analysis and qualitative uncertainty analysis. Quantitative uncertainty analysis includes random errors, such as limited data samples and measurement errors, while qualitative uncertainty analysis includes systematic errors, such as conceptualization, mode, measurement technology, and data derivation. This paper focuses on quantitative uncertainty analysis.

According to literature, uncertainty analysis has been maturely applied in the analysis and prediction of carbon emissions in line with businesses such as industry [23], agriculture [24], and transportation [25]. In the tourism industry, Liu *et al*. analyzed the uncertainty of capital strategy of tourism supply chain enterprises and simulated it with MATLAB software [26]. Han *et al*. summarized the uncoordinated factors that caused the uncertainty of ecotourism planning and proposed several improvement measures [27]. Yang *et al*. summarized the causes of the uncertainty of greenhouse gas emission estimation in China's natural wetlands [28]. With regard to the research direction of tourism carbon emissions, at present, it stops at the calculation of carbon emissions and generally lacks verification and the uncertainty analysis of carbon emission measurement data.

When conducting uncertainty analysis, the description tools that are commonly used are box uncertainty sets [23], and Monte Carlo model [24,25], SimaPro 9.0 [24], and MATLAB [26] are among the commonly used analysis tools. Generally, sensitivity analysis is carried out at the same time as uncertainty analysis. According to the data of different carbon source activities, the high-sensitivity input parameters of carbon emission are identified to provide reference for formulating emission reduction measures.

In short, it is imperative to analyze the uncertainty in the study of carbon emissions, and the essential methods and tools necessary for this are mature. The study of carbon emissions in tourist attractions generally lacks uncertainty analysis, which needs to be paid attention to [29].

4. Summary and prospect

While China's research on tourism carbon emissions generally has a solid foundation and yielded some results, there are still some problems that require further research and discussion.

4.1. Constructing a multi-spatial dimension research system

At present, the spatial scale of tourism carbon emissions research is mainly based on national, provincial, and municipal regions, and there are only a few micro-scale studies such as tourist attractions. According to the national conditions and people's conditions, we should construct a multi-spatial dimension of tourism carbon emissions research, so as to build a more perfect research system and further explore the spatial distribution of tourism carbon emissions. At the same time, with the rapid development of CCER and the national carbon market, the establishment and improvement of carbon asset accounts based on scenic spots are conducive to mobilizing the enthusiasm of scenic spots for emission reduction and to giving full play to the role of tourism in the carbon neutrality strategy.

4.2. Unified carbon emission data statistical indicators and carbon emission coefficient

Whether it is "top-down" or "bottom-up," there are inconsistent statistical indicators and inconsistent calculation methods of carbon emission coefficients. In terms of statistical indicators, some use economic income indicators, while others use energy consumption indicators as data accounting standards; in terms of carbon emission coefficient, some adopt the IPCC carbon emission coefficient method, while others adopt the standard coal coefficient method, resulting in large differences in the research results of different scholars based on the same research object and the inability to compare different research objects horizontally. We should unify the index caliber and establish a unified foundation and platform, such as the unified use of tourism satellite account research framework and data; carbon sources should be classified according to the actual situation in China, and a carbon emission coefficient calculation method should be used for the same carbon source.

4.3. Increase uncertainty analysis

At present, there is a general lack of uncertainty analysis in tourism carbon emission research, rendering inaccurate and inconclusive research results. Uncertainty analysis should be increased. Through Monte Carlo and other simulation software, the probability density function of total emissions is constructed by repeating random values of different parameters to ensure the accuracy and robustness of the research results. At the same time, the impact of different emission reduction measures on carbon emissions in scenic spots should be predicted by simulation, so as to formulate more targeted and effective emission reduction measures.

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