A Study on Sustainable Tourism Development in Juneau Based on Tourism-Economic Simulation Model

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Abstract. With the increasingly prominent environmental problems, the sustainable development of tourism has gradually become the focus of academia and industry. This study establishes a population flow ternary function model to balance tourism development and environmental protection, achieving Nash equilibrium. Based on seasonal fluctuations, cruise ship numbers, and ticket price elasticity, the model controls tourist flow. By increasing peak season ticket prices and reducing cruise ships, the model successfully controls tourist numbers during high seasons, alleviating environmental pressure. The research also constructs a tourism-economic simulation model that forecasts economic indicators for the next three decades, showing stable economic returns of approximately $35 million annually within environmental constraints. The model regulates tourism development through market mechanisms rather than public investment and demonstrates tourism's significant contribution to employment, with labor income accounting for about 52% of direct consumption. This research provides a scientific basis for developing tourism policies that balance economic benefits with sustainability goals.

Keywords: Prediction Model, Tourism Economic, Nash Equilibrium, Sustainable Development.

1. Introduction

As an important part of the global economy, tourism plays an irreplaceable role in promoting regional economic growth and creating employment opportunities. However, with the continuous expansion of the global tourism market, many tourist destinations are facing an increasingly prominent contradiction between the rapid development of tourism and the protection of resources and environment. This is also the economic contradiction facing Chengdu mentioned in [1]. In order to realize the sustainable development of tourism, there is an urgent need for a scientific method to quantitatively assess the comprehensive impact of tourism activities on the economy. Most of the traditional tourism impact assessment methods are based on static analysis, which is difficult to accurately portray the dynamic characteristics of the tourism system, and there is an urgent need to establish a new dynamic assessment model.

Taking Juneau, Alaska, USA as the research object, the rapid development of tourism in the city has brought great economic benefits. However, the rapid development of tourism has also led to the accelerated melting of Mendenhall Glacier. Studies show that 5.9 cubic kilometers of snow and ice will be lost annually between 2010 and 2020. This trend threatens not only the glacier itself but also the ecosystems that depend on it.

Glacier retreat is exacerbated by climate change and the carbon footprint of tourism activities. As stated in [2], the carbon footprint is generated by various human economic activities. The tension between economic prosperity and environmental protection requires a balanced approach to sustainable tourism management. This study begins with simulating a population mobility ternary function to balance tourism and environment by controlling for tourist flow, number of ships, and fare elasticity, and develops a tourism economic model that can provide a framework for policymakers to simulate the structure of tourist numbers, income, and expenditures to refine the structure of economic returns. According to the number of tourists predicted by the environment, the number of tourists in each year is constrained, and vibration is added to simulate the deviation of the number of tourists in each year. But at the same time, this method can only optimize a single data for reference in future years. If the environmental capacity changes, then the current predicted number of people is not the final solution, and it needs to be further optimized according to the new environmental capacity. The main goal of this study is to construct a comprehensive model to optimize tourism management in Juno, while the model can be applied to other destinations to provide a scalable solution for the management of sustainable tourism globally.

2. Construction of Tourism-Economic Simulation Model

To balance the relationship between tourism development and environmental protection to reach the Nash equilibrium point. In order to solve the contradiction similar to the use of ecological footprint model (EF) in [3]. In this paper, a population flow ternary function model is developed to control the tourist flow. The model is based on seasonal fluctuations, the number of cruise ships and ticket price elasticity, and establishes a ternary function model for predicting the number of tourists and evaluating the impact of tourists on the environment. In the model, the number of tourists is jointly affected by the season, the number of cruise ships and the ticket price. The number of tourists can be approximated as a sinusoidal function mathematical model. During the peak season, the number of tourists is controlled by adjusting the ticket price and reducing the number of cruise ships, thus alleviating the environmental pressure.

Let $T = (Se, Sh, Ti)$, where T represents the number of tourists, Se represents the seasonal low season and high season of tourism, Ti denotes the ratio of ticket price, and Sh is the number of cruise ships . So this study establish a basic equation

$$T(t) = A\sin(\omega t + \psi) + C \tag{1}$$

(1) is the model underlying the sinusoidal circulation of tourists, which requires relevant data to integrate the model. According to [4], tourism is divided into low and high seasons It is known that the overall number of tourists in 2023 is 1.6 million; the highest number of tourists in the whole year lies in July; after setting the model period to 12 months, it can construct this data as shown in (2). The following model conditions are listed:

$$\begin{cases} A < C \\ 12 = \dfrac{2\pi}{\omega} \\ 7 = \dfrac{\pi}{2} + K\pi \\ \int_{0(12)}^{12} A\sin(\omega t + \psi) + C = 1600000 \end{cases} \tag{2}$$

the seasonal model can be determined as (3):

$$T(t) = -10132\sin(\frac{\pi}{6}t + \frac{\pi}{3}) + 13333 \tag{3}$$

In addition, the curve of the sine function (3) is too smooth, and in order to characterize the stochastic nature of the number of tourists itself, this study adds a jitter error by choosing a random distribution to describe the jitter: randomly generating the magnitude of the jitter in a random direction on a monthly basis and specifying the jitter as a percentage of the total. This approach was taken to prevent excessive errors that would fail to describe the actual number of people and to ensure that the sentences remain coherent and logical.

In analyzing the number of cruise ships, the study focused on the crew capacity and fuel consumption of the ship model. A key assumption was that the seasonal distribution patterns of cruise ship numbers and tourist numbers were the same. This assumption is consistent with the validation of the data through weighted average and seasonal model fitting, where the ship's share of the total tourist impact is taken from verified sources.

Meanwhile, in terms of tickets, based on statistical knowledge, it is understood that there is an elasticity of thought among tourists with respect to tickets. A variable or coefficient can be defined to represent the ratio of the magnitude of the change in the ticket price to the price of the ticket itself. Specifically, it can be expressed as: Fare change ratio is tantamount to $\frac{\Delta P}{P}$.

where ΔP is the amount of change in the fare and P is the original fare. This ratio describes the percentage change in fares

For tourists define the elasticity of demand ρ, $\rho = -0.2$ expressed as a decrease in the number of tourists by 0.2% for every 1% increase in fares. Inspired by literature [5]. The rate of change in the number of tourists can be expressed as:

$$V = (1 - \rho \frac{\Delta P}{P}) \tag{4}$$

It can be seen from the Table 1 below the number of travellers in the last 24 years.

Assuming a demand elasticity of -0.7 in summer and -0.4 in spring and fall off-season, bringing the data into (4) allows us to calculate the rate of change of the number of tourists in each season V_1, V_2, V_3 ,setting $V = V_1 \times V_2 \times V_3$ as the fare elasticity-adjusted demand . By combining the number of tourists and the number of boats with the elasticity of demand and adjusting the weight classification, the total number of tourists under the combined factors can be determined:

$$\text{total} = \left(0.9 \times \mathrm{f}_{visitor} + 0.1 \times \mathrm{f}_{ship}\right) \times V \tag{5}$$

Through equation (5), the corresponding total number of visitors can be calculated. After that, a map of seasonal traveler flows is obtained, along with seasonal total visitor flows, through a combination of factors. As shown in Figure 1. Figure 1 shows the distribution of tourists before and after the optimization of glacier tourism environment.

3. Analysis and Prediction of Tourism Development's Impact on Local Economy

The development of tourism will promote the development of local tertiary services, which will bring not only economic benefits but also employment opportunities. This economic benefit is divided into direct and indirect economies, with the direct economy comprising three major components: tourist arrivals and economic revenues, municipal revenues, and cruise industry expenditures (crew expenditures, others); it can be expressed succinctly in a mathematical formula:

$$R_{\text{direct}} = N \cdot (C_{\text{visitor}} + T_{\text{tax}}) + E_{\text{cruise}} \tag{6}$$

Where N denotes the number of tourists, C_{visitor} denotes per capita spending on accommodation, food and drink, and sightseeing tickets, and also includes spending on crew and harbour dues E_{cruise}, as well as municipal revenues through taxation T_{tax} .Equation (6) visualizes the sources of direct economic.

The indirect economy of tourist arrivals, which encompasses economic impacts, employment, labor income, and total expenditure, is not directly derivable from the data. However, a simple linear model can be constructed to represent the relationship between these factors in [6].

$$\mathrm{R}_{\text{indirect}} = \alpha \cdot \mathrm{R}_{\text{direct}} + \beta \cdot \mathrm{L} \tag{7}$$

Equation (7) reflects the relationship between indirect and direct economic income and jobs, which is set as the driving coefficient, mainly reflecting the driving effect of external tourism income on the local industry, and the positive correlation between jobs and the number of tourists, which is set as the per capita production labor contribution rate. According to the literature [7], there is indeed a certain fitting relationship between the local economy and the number of tourists, but the economic structure of different regions is different. All these data need to be derived from local field surveys and fitted by statistical data.

Based on the research of literature [8], this paper constructs a cruise tourism policy transition mechanism to cope with the revenue risk caused by changes in fares, taxes and consumption structure by setting an annual share adjustment threshold (±10%). Taking Juneau's 2023 food and beverage consumption rate (35-45%) as the dynamic observation window, we design a progressive environmental tax reform programme: stepwise increase in the tax rate of high-carbon activities while subsidising low-carbon projects, combining the multi-dimensional assessment indicators of economic returns, carbon emissions and social acceptance to form a fiscal stability regulation system. The model simplifies the calculation of the economic linkage between tourists and employment through linearisation assumptions, and achieves a dynamic balance between economic benefits and sustainability goals through carrying capacity constraints and interference simulation, providing a scientific basis for policy implementation.

Research indicates cruise costs follow historical trends with steady rises. Low sensitivity of cruise fleet size and economic conditions may lead to volatility under adverse scenarios, while moderate crew expenditure growth aligns with stable historical patterns, ensuring reliable forecasts. High sensitivity of visitor numbers and consumer preferences necessitates dynamic strategies, including tourism product diversification to mitigate risks—validating tax policy feasibility per literature [9]. Economic sensitivity underscores fiscal regulation importance. Figure 3 quantifies optimized consumption trends across parameters.

3.1. The Establishment of Simulation Model

The Tourism-Economic Simulation model was implemented using a MATLAB-based framework, generating projected data for the next three decades, including sectoral consumption ratio distributions (visualized as pie charts) and annual consumption trends. The simulation model comes from [10]. Chart Tourism Activity Radio =0.4192; Catering Radio=0.0875; Retail Radio=0.3722; Transport Radio=0.0420; Other Radio=0.0191; Government Radio=0.0100.

3.2. Analysis of Experimental Results

Figure 1 shows the number of tourists in each month before and after optimization. In the peak season month, the fare is fully increased and the number of ships is reduced to control the number of tourists. Figure 2 shows the consumption proportion of tourists in the current paper, which can be modified to simulate macro-tourism economic regulation and control for different task environments. Figure 3 shows the current forecast annual economic consumption indicators under the proportion of consumption in Figure 2. Through this index, and changing the monthly distribution of tourist numbers in Figure 1 and the proportion of Figure 2, this model can be competent for a variety of optimization tasks.

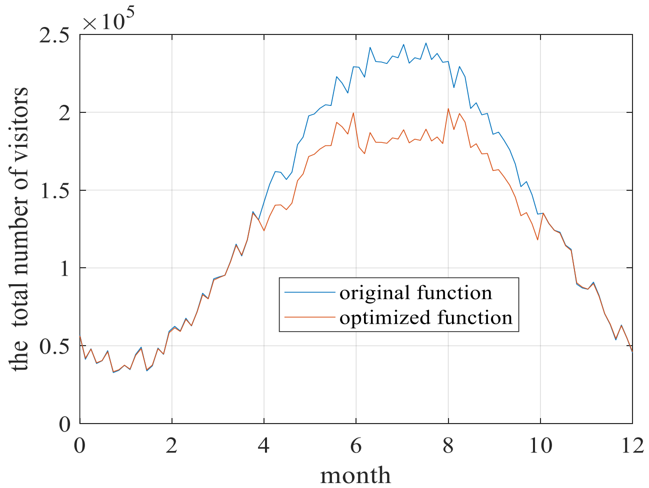

Figure 1. Distribution of the number of people before and after optimization

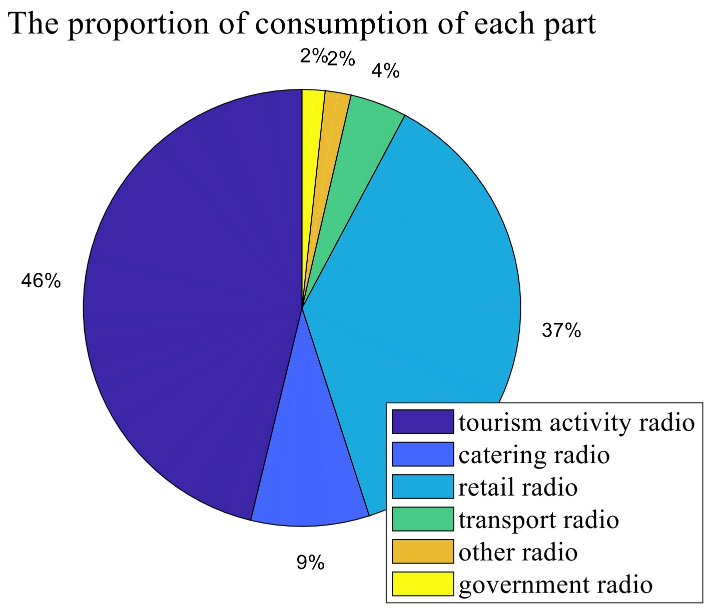

Figure 2. Pie chart of consumption ratio of each component

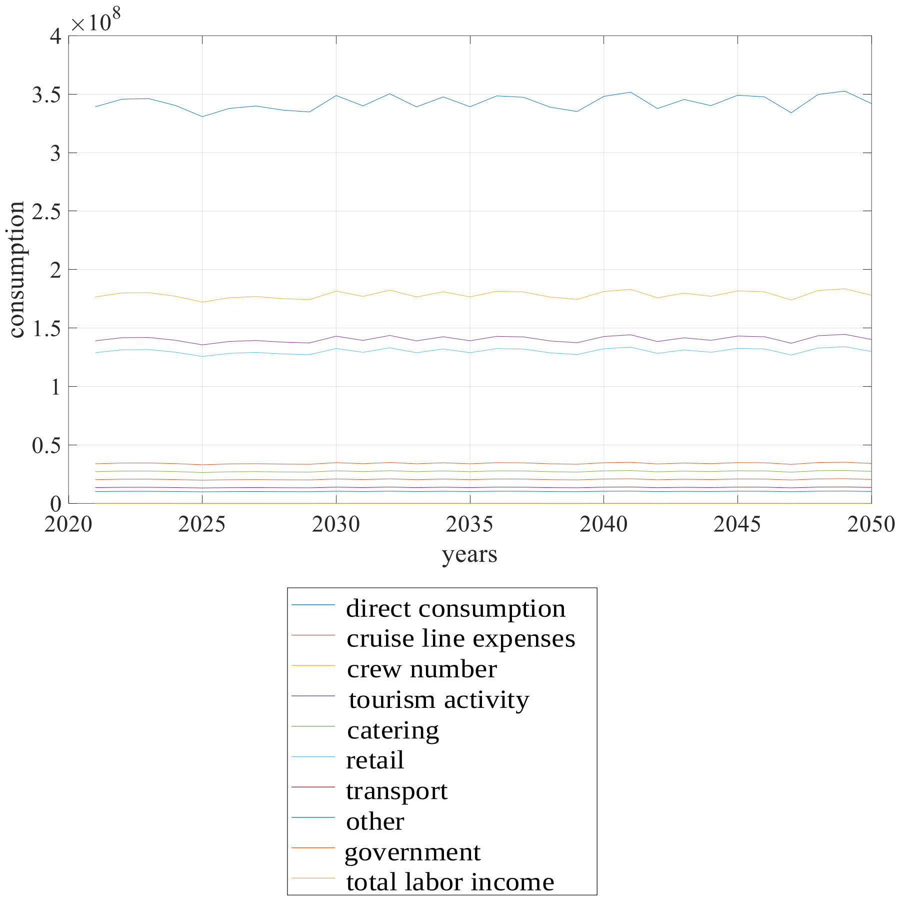

Figure 3. indicates the consumption trends and specific numbers in various aspects after optimization.

3.3. Relevant forecast data

Table 1 shows the annual demographic data from 2000 to 2023, with the number of people increasing from 414,000 to 1.65 million, a nearly four-fold increase, and Table 2 forecasts the economic indicators, which generally oscillate slightly around the $350 million target, in line with the model's goal of ‘stable returns within environmental constraints’. In Tables 3 and 4, cruise costs account for about 10 per cent of direct consumption, and crew wages are highly positively correlated. Tables 5, 6, 7, 8, and 9 show the corresponding consumption structure forecasts, highlighting the importance of non-ticket revenues in contributing to the economy, and the fact that the modelling relies more on market mechanisms than on public investment. Table 10 shows labour income, which accounts for about 52% of direct consumption, demonstrating the strong contribution of tourism to employment.

Table 1. The Number of Tourists per Year (2000~2023)

Years	Numbers	Years	Numbers	Years	Numbers	Years	Numbers
2000	413,841	2006	455,365	2012	496,888	2018	942,281
2001	420,762	2007	462,285	2013	503,809	2019	1,083,825
2002	427,682	2008	469,206	2014	510,729	2020	1,225,369
2003	434,603	2009	476,126	2015	517,650	2021	1,366,913
2004	441,524	2010	483,047	2016	659,194	2022	1,508,456
2005	448,444	2011	503,809	2017	800,738	2023	1,650,000

Table 2. Predicted Average Direct Consumption (2023~2050)

Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)
2023	34.62	2030	34.886	2037	34.735	2044	34.022
2024	34.03	2031	34.002	2038	33.884	2045	34.912
2025	33.077	2032	35.035	2039	33.52	2046	34.767
2026	33.779	2033	33.915	2040	34.815	2047	33.41
2027	33.99	2034	34.767	2041	35.173	2048	34.976
2028	33.643	2035	33.928	2042	33.772	2049	35.265
2029	33.478	2036	34.856	2043	34.547	2050	34.193

Table 3. Predicted Average Cruise Line Expenses (2023~2050)

Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)
2023	3.462	2030	3.4886	2037	3.4735	2044	3.4022
2024	3.403	2031	3.4002	2038	3.3884	2045	3.4912
2025	3.3077	2032	3.5035	2039	3.352	2046	3.4767
2026	3.3779	2033	3.3915	2040	3.4815	2047	3.341
2027	3.399	2034	3.4767	2041	3.5173	2048	3.4976
2028	3.3643	2035	3.3928	2042	3.3772	2049	3.5265
2029	3.3478	2036	3.4856	2043	3.4547	2050	3.4193

Table 4. Predicted Average Crew Number Expenses (2023~2050)

Years	Consumption (dollar$)	Years	Consumption (dollar$)	Years	Consumption (dollar$)	Years	Consumption (dollar$)
2023	31,158	2030	31,397	2037	31,262	2044	30,620
2024	30,627	2031	30,602	2038	30,496	2045	31,421
2025	29,770	2032	31,531	2039	30,168	2046	31,290
2026	30,401	2033	30,524	2040	31,334	2047	30,069
2027	30,591	2034	31,290	2041	31,656	2048	31,479
2028	30,278	2035	30,535	2042	30,395	2049	31,738
2029	30,130	2036	31,370	2043	31,092	2050	30,774

Table 5. Predicted Average Catering Expenses (2023~2050)

Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)
2023	2.7696	2030	2.7909	2037	2.7788	2044	2.7218
2024	2.7224	2031	2.7202	2038	2.7107	2045	2.793
2025	2.6462	2032	2.8028	2039	2.6816	2046	2.7813
2026	2.7023	2033	2.7132	2040	2.7852	2047	2.6728
2027	2.7192	2034	2.7814	2041	2.8139	2048	2.7981
2028	2.6914	2035	2.7142	2042	2.7017	2049	2.8212
2029	2.6782	2036	2.7885	2043	2.7637	2050	2.7354

Table 6. Predicted Average Tourism Activity Consumption (2023~2050)

Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)
2023	14.194	2030	14.303	2037	14.242	2044	13.949
2024	13.952	2031	13.941	2038	13.892	2045	14.314
2025	13.562	2032	14.364	2039	13.743	2046	14.254
2026	13.849	2033	13.905	2040	14.274	2047	13.698
2027	13.936	2034	14.255	2041	14.421	2048	14.34
2028	13.793	2035	13.91	2042	13.846	2049	14.459
2029	13.726	2036	14.291	2043	14.164	2050	14.019

Table 7. Predicted Average Retail Rate (2023~2050)

Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)
2023	13.156	2030	13.257	2037	13.199	2044	12.928
2024	12.932	2031	12.921	2038	12.876	2045	13.267
2025	12.569	2032	13.313	2039	12.738	2046	13.211
2026	12.836	2033	12.888	2040	13.23	2047	12.696
2027	12.916	2034	13.212	2041	13.366	2048	13.291
2028	12.784	2035	12.893	2042	12.833	2049	13.401
2029	12.721	2036	13.245	2043	13.128	2050	12.993

Table 8. Predicted Average Transport Rate (2023~2050)

Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)
2023	1.3848	2030	1.3954	2037	1.3894	2044	1.3609
2024	1.3612	2031	1.3601	2038	1.3554	2045	1.3965
2025	1.3231	2032	1.4014	2039	1.3408	2046	1.3907
2026	1.3512	2033	1.3566	2040	1.3926	2047	1.3364
2027	1.3596	2034	1.3907	2041	1.4069	2048	1.3991
2028	1.3457	2035	1.3571	2042	1.3509	2049	1.4106
2029	1.3391	2036	1.39421	2043	1.3819	2050	1.3677

Table 9. Predicted Average Government Rate (2023~2050)

Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)
2023	2.0772	2030	2.0931	2037	2.0841	2044	2.0413
2024	2.0418	2031	2.0401	2038	2.033	2045	2.0947
2025	1.9846	2032	2.1021	2039	2.0112	2046	2.086
2026	2.0267	2033	2.0349	2040	2.0889	2047	2.0046
2027	2.0394	2034	2.086	2041	2.1104	2048	2.0986
2028	2.0186	2035	2.0357	2042	2.0263	2049	2.1159
2029	2.0087	2036	2.0914	2043	2.0728	2050	2.0516

Table 10. Predicted Average Total Labor Income (2023~2050)

Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)	Years	Consumption (million$)
2023	18.024	2030	18.162	2037	18.084	2044	17.713
2024	17.717	2031	17.703	2038	17.641	2045	18.176
2025	17.221	2032	18.24	2039	17.451	2046	18.1
2026	17.586	2033	17.657	2040	18.126	2047	17.394
2027	17.696	2034	18.101	2041	18.312	2048	18.21
2028	17.515	2035	17.664	2042	17.582	2049	18.36
2029	17.429	2036	18.147	2043	17.986	2050	17.802

4. Conclusion

In this study, a tourism economic simulation model was constructed to balance the economic benefits and environmental sustainability of a glacier-based tourist city. By incorporating seasonal fluctuations, fare elasticity, and cruise ship capacity into a ternary function, the model dynamically optimizes the number of tourists, employs the Nash equilibrium condition to derive the number of saturated tourists, and also predicts the tourism economic revenue until 2050 under the condition that the number of tourists is close to the Nash equilibrium condition, which maintains the annual direct consumption at around US$3.5 million without damaging the environment. Data validation relies heavily on historical trends, which may not fully reflect future uncertainties such as extreme climate or geopolitical changes. Future research could enhance robustness by incorporating stochastic climate models, multi-agent behavioral simulations, and cross-regional comparative studies.

This study provides an extensible framework for sustainable tourism management, demonstrating the feasibility of incorporating dynamic simulation models into policy design. The approach combines demand elasticities, seasonal controls and macroeconomic forecasts to provide actionable insights for tourism destinations facing similar trade-offs between economic growth and environmental protection. By adjusting variables such as tax structures or carbon taxes, this approach can guide global tourism management towards long-term sustainable development goals.

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