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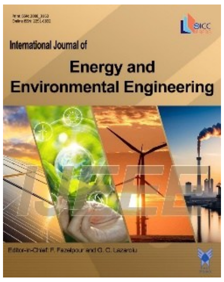

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Energy Consumption and Sustainable Development of the Tourism Industry: A Study from a Global Perspective

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Original Research

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Abstract

Energy consumption will cause environmental pollution to intensify, affect the development of modern tourism, and a large number of tourism behaviors will also exacerbate carbon emissions, so new energy technologies such as wind power and photovoltaic can promote the sustainable development of tourism and balance the relationship between social development and entertainment consumption. This paper examines the relationship between green energy and the tourism industry, focusing on wind and photovoltaic power to optimize tourism energy structures and broaden renewable applications. Results indicate that photovoltaic and wind generation fluctuates but remains stable, while rising tourism energy demand is offset by renewables, reducing consumption without harming operations or economic benefits. Tourism energy use peaks between 13:00–18:00, when photovoltaic supply is stable and maximal; demand grows from 8:00–13:00; and from 18:00–24:00 photovoltaic output declines while wind power provides storage. Savings increase with photovoltaic shares up to 50%. Energy stability reaches 70–75%, and satisfaction ranges from 65.32–85.36%. Therefor the sustainable development of new energy can enhance the sustainability of tourism, promote its development in the direction of energy conservation and environmental protection, and improve the integration level of electricity and tourism.

Keywords: Energy consumption, Tourism industry, Sustainable development, Green innovation, Economic growth, Environmental sustainability, VAR model

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1. Introduction

Today, the tourism economy has become a supporting industry in the gross national product, with annual carbon emissions from travel reaching 145 million tons/day, accounting for 5.6% of total energy consumption [1, 2]. Therefore, it is generally believed that reducing tourism carbon emissions can enhance the sustainability of tourism development and increase social economic benefits. However, there are differences in travel around the world, and unified planning and management cannot be achieved, so new energy technologies should be expanded to enrich the forms of energy generation [3]. Some scholars believe that the VAR model is used to predict the marginal consumption propensity of tourism and the proportion of new energy applications, so as to determine the sustainable development of tourism and the relationship between energy structure and tourism [4]. It is also believed that exploring the differences in the spatial effects of inbound tourism on carbon emissions and finding differences in the use of new energy in different regions can provide corresponding suggestions for the development of new energy [5,6]. In the process of new energy determination, the dominance of photovoltaic and wind power in the tourism industry was studied through univariate linear regression and gray correlation analysis, and the relationship between energy consumption and sustainable development of tourism was revealed [7]. International environmental protection organizations have proposed that energy consumption and tourism can be integrated to improve the emission reduction effect of tourism, realize the integration of tourism with industrial development and socio-economic development, and promote the integration of primary, secondary and tertiary industries [8-10]. At present, the tourism market pays too much attention to economic benefits, although the globalization of tourism is expanded, but there is a bottleneck in the development of the emission reduction effect of tourism, which is rooted in the fact that the energy structure of the global tourism system is still petrochemical resources, which reduces the sustainability of tourism development. Based on this background, this paper conducts a regression analysis of new energy and tourism development from three aspects, calculates the relationship between total tourism carbon emissions and the application ratio of new energy, and verifies the positive role of new energy on the sustainable development of tourism through practical cases. Firstly, the VAR model was used to explore the data relationship between energy consumption and tourism. Then, analyze the relationship between photovoltaic, wind power generation and tourism. Finally, by adjusting the proportion of photovoltaic and wind power generation, the proportion of tourism development operations is analyzed, and the deep relationship between energy structure and tourism is explained.

2. Analysis of photovoltaic and wind energy inputs and sustainable development of tourism

2.1. Energy supply of photovoltaic and wind power generation

The VAR model is mainly used to predict the sustainability of photovoltaic and wind power generation, and to study the dynamic influence of random interference factors (voltage and current changes) on the output power flow. The basic idea of the VAR model is to build a model by statistically stating the output of new energy generation in each time period and adding the lag coefficient function, so as to avoid the influence of interference factors on the total energy output in the new energy structure

$$y_t = v + A_1 y_{t-1} + \cdots + A_p y_{t-p} + B_0 x_t + B_1 x_{t-1} + \cdots + B_q x_{t-q} + \mu_t t \in \{-\infty, +\infty\} \quad (1)$$

In the equation, $y_t = (y_{1t} \cdots\cdots y_{Kt})$ is the random vector of order K×1, representing the power flow in different time periods, the total tidal change is the K×order parameter matrix,A_1 is the exogenous variable vector of M×1 order photovoltaic power generation, A_p is the coefficient matrix to be estimated of K×M order wind power generation, B_q is the interference of light time and wind strength,μ_t is the influence coefficient of new energy power generation on tourism, and t is the time of new energy power generation.The relationship function between tourism energy demand and new energy is constructed, as shown in Equation (2).

$$E(\mu_t) = 0, E(\mu_t \mu_t') = \sum E(\mu_t \mu_s'), \text{ and } E(\mu_t \mu_s') = 0, (t \neq s) 。 \quad (2)$$

In the formula, due to the lag is strong enough μ_t, the dynamic contact information of the travel can be comprehensive. However, in the energy balance problem, if the delay is too long, the interference parameters will increase and the degrees of freedom will decrease accordingly. Therefore, in this study, the equilibrium state coefficient is added, the light intensity, time, and wind intensity are calculated, and the lag period of the minimum statistic can be calculated by referring to Equation (2) and Equation (3).

$$AIC = -2l/n + 2k/n \quad (3)$$

And

$$SC = -2l/n + k \log n / n \quad (4)$$

In the equation, $AIC$is the light intensity, $k$the parameter to be estimated, $l$is the hysteresis condition analysis,SC is the wind intensity, and n represents the number of samples observed. For the lag condition analysis, it is necessary to make multi-cause judgment to ensure the balance between output and input, and the cause analysis is shown in Equation (5).

$$l = -\frac{nm}{2}(1 + \log 2\pi) - \frac{n}{2} \log[\det(\sum_t \hat{\varepsilon}_t \hat{\varepsilon}_t'/n)] \quad (5)$$

Among them, $\log 2\pi$ represents the cycle of new energy power generation,.$\hat{\varepsilon}_t$ is the increase in energy consumption of tourism, and $\hat{\varepsilon}_t'$ is the impact of new energy on tourism consumption

2.2. The power generation structure of new energy is related to the sustainability of tourism

2.2.1. *The proportion of photovoltaic power generation has increased*

Photovoltaic power generation is obviously affected by sunlight exposure, and sunlight exposure is affected by weather and time, so the parameters are optimized to judge the changes in different times, and the calculation is shown in Equation (6).$AICAIC$

$$AIC \cdot \left|\hat{\Sigma} l\right| = det(\frac{1}{T-m}) \sum_t (\hat{\varepsilon}_t \hat{\varepsilon}_t') \quad (6)$$

Among them,.$det(\frac{1}{T-m})$ is the photovoltaic power generation effect,T is the power generation lag time, and$\sum_t (\hat{\varepsilon}_t \hat{\varepsilon}_t')$ is the illumination angle are all quantified indicators, $\left|\hat{\Sigma} l\right|$ is addition and subtraction analysis can be carried out. On the basis of lag time and angle change, the lighting effect is sustained. In order to simplify the calculation process, the tourism energy consumption function is used as the basis for analysis, so it represents the continuous energy consumption of tourism, which is the basis for calculating the proportion of photovoltaics, and calculates its change process. It is the lag coefficient of photovoltaic power generation, which has a constraint on the calculation of the proportion of photovoltaics$m$ (2) The energy span of the highest and lowest points of photovoltaic power generation It is necessary to calculate the daily energy difference of photovoltaic power generation, and to calculate the energy span of the time span, the calculation process is shown in Equation (7).

$$\sum Q_i = \sum \frac{T}{2} k(1 + log\, 2\pi) \cdot log \left|\hat{\sum} q\right| \quad (7)$$

Among them, $\frac{T}{2}$ is the half-period value of photovoltaic power generation, $\hat{\sum} q$ is continuously calculated under the action of the constraint coefficient k, and$\sum Q_i$ is the cycle energy is reduced to avoid extreme values. Then,$def(\sum Q_i)$ is the power of photovoltaic power generation is continuously collected to form an aggregate. It is the total energy of photovoltaic power generation. Finally, it is subdivided and obtained, that is, the energy span.

2.2.2. *The proportion of wind power generation has increased*

The proportion of wind power generation will also have an impact on tourism energy consumption, wind power generation is obviously affected by seasonality and less affected by sunshine, so to analyze the impact of wind power generation, it is necessary to increase the test time, and the calculation is shown in Equation (8).

$$\sum M_i = m_i \cdot \frac{T}{4} \cdot \lambda(1 + log\, 2\pi) \quad (8)$$

Among them, $\sum M_i$ is the total energy of wind power generation, m_i is the wind power generation of the day, andλ is the change indicator of wind speed and intensity. Relatively speaking, wind power generation has fewer influencing factors and more stable power generation. However, wind power accounts for a small proportion. To sum up, the output proportion of wind and photovoltaic power generation and the impact on tourism energy consumption still return to the total aspect, which can constitute a joint energy consumption formula, as shown in Equation (9).

$$\begin{cases} \sum AIC = \sum Q_i + \sum M_i\,, \ \ \Delta AIC > 0 \\ \sum SC = -AIC \cdot \left|\hat{\Sigma} l\right| + n\, log\, T\, /T, SC < 1/2 \end{cases} \quad (9)$$

Among them,$\sum AIC$ is the consumption of photovoltaic power generation and$\sum SC$ is wind power generation.$\sum SC$ is also affected by photovoltaic power generation and belongs to auxiliary power generation.

2.3. Constraints on the analysis of the sustainable impact of new energy on tourism

$\sum AIC$ is the effect of photovoltaic and wind power generation,.$\sum SC$ is energy consumption constraints are carried out,$\sum M_i$ is mainly to reduce the energy consumption min (+) of tourism, $\sum Q_i$ is increase the proportion of new energy max (+), and achieve a balance between the two, as shown in Equation (10)

$$\min\ (\sum AIC + \sum SC)\ -\max(\sum M_i + \sum Q_i) > 0 \quad (10)$$

At the same time, the equilibrium factor is increased to achieve a balance between the two, as shown in Equation (11).

$$k \cdot [\min\ (\sum AIC + \sum SC \approx)\ ] \approx k[\max(\sum M_i + \sum Q_i)] \quad (11)$$

3. Practical case analysis

3.1. Data sources and processing

In this study, the travel consumption of international tourism and the energy consumption of photovoltaic and wind power generation were analyzed as the research objects, and the energy consumption degree between the two was calculated. For ease of calculation, 30% of tourism revenue is used as the calculated value of energy consumption and divided by the current oil price. The data collection time is based on the total global tourism revenue and actual international oil prices between 2022 and 2024, and is continuously compared. Among them, the power generation of new energy sources such as photovoltaic and wind power accounts for 10.63% of the total power generation, so the analysis is based on international power generation. The main disturbing factors are the proportion of international price increases, natural disasters, and people's subjective cancellation of tourism. Therefore, fuzzy analysis is used for processing, and the abnormal data and missing data in the data collection are fully filled to form complete data values.

3.2. Results of the impact of photovoltaic and wind energy on tourism sustainability

Photovoltaic and wind power generation are unstable, so to meet the energy consumption output of travel, it is necessary to calculate the relationship between new energy output and tourism consumption to form a stable data value, as shown in Figure 1. As can be seen from Figure 1, the new energy power generation of photovoltaic and wind power continues to fluctuate, and the power generation is relatively stable. The continuous increase in tourism energy consumption indicates that the proportion of photovoltaic and wind power has increased, which can reduce the energy consumption of tourism. At the same time, tourism work has not been affected, and the overall economic benefits are stable. It shows that photovoltaic and wind power generation can replace petrochemical energy and meet the consumption demand of tourism energy. The VAR model was used to analyze the balance between tourism energy consumption and new energy energy consumption, and the results are shown in Table 1. From the data in Table 1, it can be seen that the increase of photovoltaic and wind energy continues to increase, and the total energy consumption of travel is greater than that of photovoltaic + wind, and the energy difference between the two is stored in the storage pool to maintain the energy balance between travel and power generation. In addition, the total increase in photovoltaic and wind power generation indicates that tourism energy consumption is developing in the direction of new energy and carbon emissions are decreasing.

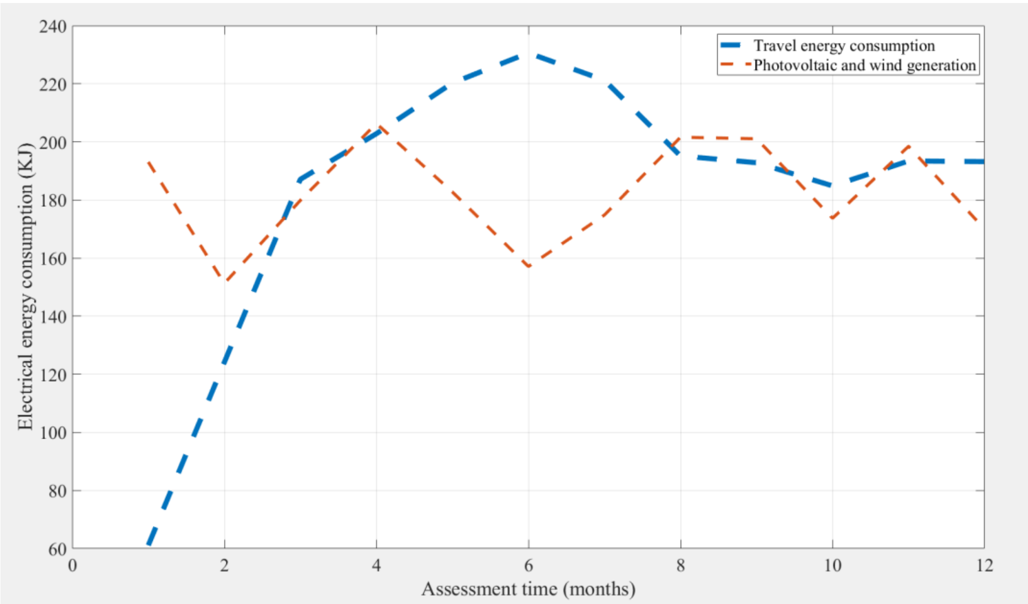

Figure 1. The energy balance between travel energy consumption and new energy generation

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Table 1. Balance relationship between tourism and new energy consumption

Tourist area	Photovoltaic energy		Wind energy				
	Energy utilization	Energy increase	Energy utilization	Energy increase	Energy storage	Travel energy consumption	Carbon emissions
This area	16.17±0.41	rise	10.32±0.92	rise	8.74±1.05	31.63±0.15	decline
Cross-regional	72.40±0.92	rise	11.32±0.26	rise	4.44±0.66	94.87±0.24	decline
Local + cross-regional	82.21±0.80	rise	9.29±0.63	rise	24.07±0.51	104.82±0.46	decline

4.2 The impact of structural optimization of photovoltaic and wind energy on tourism energy demand

Photovoltaic and wind energy are affected by the season and light, and the energy output is different, while the energy required for tourism is relatively stable, so it is necessary to ensure the amount of tourism energy consumption. Among them, the energy consumption of tourism is mainly during the day, and the consumption at night is relatively small, which can be compared and analyzed according to the energy consumption within 24 hours, as shown in Figure 2. It can be seen from Figure 2 that tourism energy consumption is highly volatile, between 13:00~18:00 in the afternoon, the energy consumption is large, and the supply of photovoltaic energy is stable and reaches the maximum value. Between 8:00~13:00 a.m., tourism consumption continues to increase, while wind power generation is stable, which can provide electrical energy support for tourism consumption. Between 18:00~24:00, the photovoltaic power generation reaches the minimum value, and the wind power generation is stable, which can support the next day's tourism consumption and store more energy. This shows that photovoltaic and wind power generation can provide stable energy for tourism, stable wind output, and large photovoltaic output. The synergy between photovoltaic and wind power generation is analyzed, and the results are shown in Table 2. Table 2 shows that there is a strong correlation between photovoltaic, wind energy structure and tourism energy demand. The impact of photovoltaic power generation on daytime activities was high, ranging from 0.85±0.11, and the impact on nighttime activities was small. However, through the combination of wind + photovoltaic power generation, the impact of daytime activities increased significantly, reaching 0.96±0.13, and the nighttime activity decreased slightly to 0.86±0.23. All-day photovoltaic + wind power generation can improve the impact of daytime activities to a limited extent of 0.97±0.22, and the increase of nighttime activities is limited to 0.82±0.12, so photovoltaic daytime + wind power can meet the energy demand of tourism, and the energy structure is more reasonable.

4.3 The sustainable role of photovoltaic and wind new energy on tourism

Based on the above analysis, the sustainable role of photovoltaic and wind power on tourism is judged mainly in two aspects, the cost of energy consumption, the stability of energy consumption, and the satisfaction of tourism energy consumption, the specific results are shown in Table 3. From Table 3, it can be seen that the continuous role of new energy such as photovoltaic and wind power in tourism is reflected in three aspects, and the cost saving will increase with the proportion of photovoltaic power generation, but the proportion of photovoltaic power generation reaches the maximum value of 50%; The stability of energy consumption is good, about 70~75%; The satisfaction rate of tourism energy consumption is between 65.32~85.36%. The higher the proportion of photovoltaic power generation, the greater the cost saving, energy consumption stability and energy consumption satisfaction rate of the tourism industry. However, the proportion of wind power generation also has a supporting role and can improve the sustainability of tourism. Therefore, the energy structure has a significant role in the sustainability of tourism, the increase in the proportion of photovoltaics is higher, and the wind power is relatively less, but the wind power is more sustainable.

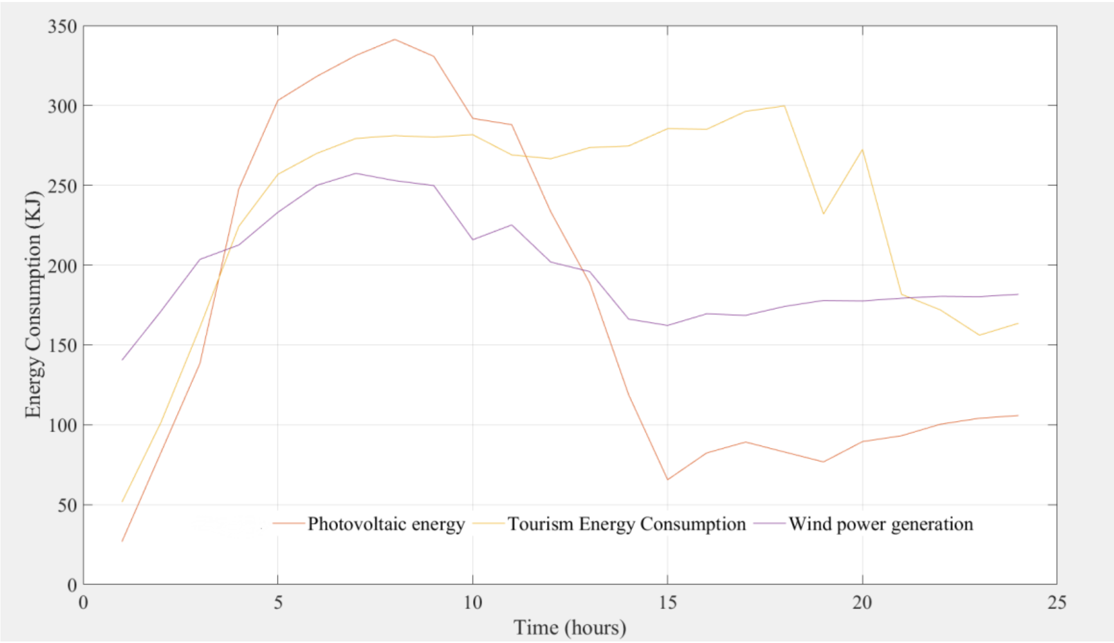

Figure 2. The relationship between photovoltaic and wind energy structure and tourism energy demand

Table 2. Correlation between photovoltaic and wind energy structure and tourism energy demand

Energy form	Time	Daytime tourism activities	Night tour activities	Full-day tour activities
Photovoltaic power generation	daytime	0.85±0.11	0.12±0.16	0.86±0.13
Wind power	Day + night	0.78±0.25	0.76±0.1	0.65±0.11
Wind + photovoltaic Up to 2	Photovoltaic day + wind night	0.96±0.13	0.86±0.23	0.72±0.02
	Photovoltaic daytime + wind power all day	0.97±0.22	0.82±0.12	0.72±0.06

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Table 3. The sustainable role of photovoltaic and wind new energy on tourism

The proportion of photovoltaic and wind power	Sustainability of tourism		
	Cost savings	Stable energy consumption	Tourism energy consumption satisfaction rate
Photovoltaic 20% + Wind 80%	20.63±2.32	75.36±2.36	75.36±1.36
Photovoltaic 40% + Wind 60%	40.32±1.62	74.63±1.32	85.36±4.32
Photovoltaic 60% + Wind 40%	60.77±2.06	70.96±2.33	77.66±5.36
80% photovoltaic + 20% wind power	60.77±3.06	73.36±4.32	65.32±1.32
Photovoltaic 50% + Wind 50%	61.32±4.32	75.36±3.26	71.65±0.65

Declarations

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Conflict of Interest

The authors declare that they have no conflicts of interest regarding this work.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Code availability

Not applicable.

Authors Contribution
All authors have contributed equally to prepare the paper.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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