J. Resour. Ecol. 2023 14(5): 1053-1060
DOI: 10.5814/j.issn.1674-764x.2023.05.016
www.jorae.cn

Tracking the Drivers of the Tourism Ecological Footprint in Mount Wutai, China, based on the STIRPAT Model

LUO Shuzheng[1,*], YIN Jianshu[2], BAI Hailong[3], CAI Fuyan[4]

1. Department of Biological Sciences, Xinzhou Normal University, Xinzhou, Shanxi 034000, China;
2. Mount Wutai Scenic Area Planning and Research Center, Xinzhou, Shanxi 034000, China;
3. Cultural Relics and Heritage Protection Bureau of Mount Wutai Scenic Area, Xinzhou, Shanxi 034000, China;
4. College of Applied Engineering, Urumqi Vocational University, Urumqi 830002, China

Abstract: Tourism can cause serious environmental pollution due to high consumption levels. With the development of tourism in Mount Wutai, the environmental pressure has been increasing. This study explored the influences of tourist arrivals in Mount Wutai, ticket revenue from domestic tourists in Mount Wutai, national passenger turnover, energy intensity, GDP per capita in Wutai County and GDP per capita in China on the tourism ecological footprint in Mount Wutai from 2005 to 2019. The extended STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model was constructed by using principal component regression. The results were as follows: (1) The tourism ecological footprint in Mount Wutai increased during the study period, from 27798.07 gha in 2005 to 67467.36 gha in 2019. (2) From 2005 to 2019, tourist arrivals in Mount Wutai, ticket revenue from domestic tourists in Mount Wutai, national passenger turnover, GDP per capita in Wutai County and GDP per capita in China grew, while energy intensity declined. (3) The extended STIRPAT model showed that the elasticity coefficients of tourist arrivals in Mount Wutai, ticket revenue from domestic tourists in Mount Wutai and national passenger turnover were 0.086%, 0.075% and 0.164%, respectively, which indicated that the tourism ecological footprint in Mount Wutai would increase by 0.086%, 0.075% and 0.164%, respectively, when those parameters increased by 1%; the elasticity coefficients of GDP per capita in Wutai County and GDP per capita in China increased at an escalating pace, but the environmental Kuznets curve did not exist, indicating that economic growth did not alleviate the environmental pressure during the study period; the elasticity coefficient of energy intensity was –0.108%, which indicated that the tourism ecological footprint would decrease by 0.108% when energy intensity increased by 1%. Therefore, the implementation of effective policies and technological innovation would significantly reduce the tourism ecological footprint in Mount Wutai.

Key words: STIRPAT; tourism ecological footprint; principal component regression; drivers

1 Introduction

Humans are modifying the global environment on an unprecedented scale. However, the ways in which anthropogenic drivers impact environment are not fully understood due to a paucity of powerful analytic tools (York et al., 2003). This limitation impedes the adoption of reasonable measures to lessen the human impact on the environment. To deal with this dilemma, the STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model has been developed to mathematically delineate the driving forces and their environmental impacts. Dietz and Rosa (1994) discussed the beneficial features and limitations of the widely known IPAT model, and reformulated it in a stochastic form in order to more effectively analyze

Received: 2023-01-25 **Accepted:** 2023-04-22
Foundation: The Xinzhou Teachers University Project (2018KY02); The Program for the Philosophy and Social Sciences Research of Higher Learning Institutions of Shanxi (20190131).
*Corresponding author: LUO Shuzheng, E-mail: luoshuzhengyan@163.com

Citation: LUO Shuzheng, YIN Jianshu, BAI Hailong et al. 2023. Tracking the Drivers of the Tourism Ecological Footprint in Mount Wutai, China, based on the STIRPAT Model. *Journal of Resources and Ecology*, 14(5): 1053–1060.

how population, affluence and technology drive environmental impacts. Rosa and Dietz (1998) named this stochastic reformulation STIRPAT and emphasized its merits. York et al. (2003) improved the STIRPAT model by expounding ecological elasticity, which refers to the sensitivity of the environmental impact to the drivers, and offered users a powerful tool for interpreting and comparing the effects of different drivers more precisely. In more and more studies, the STIRPAT model is being extended to capture more drivers of environmental impacts. Environmental impacts have been measured by ecological footprint and CO_2 emissions in many studies. Dietz et al. (2007) analyzed the effects on the ecological footprint of total population, population composition, GDP per capita, economic structure, education, life expectancy and land area per capita in 20 countries and emphasized the importance of increasing resource use efficiency. Solarin et al. (2021) found that foreign direct investment and trade increased the ecological footprint in the long run while economic growth reduced it in Nigeria, and recommended that powerful policy directions should regulate environmental deterioration. Usman and Hammar (2021) proposed that cleaner innovation, financial funds and demographic policies could mitigate the ecological footprint in the Asia Pacific Economic Cooperation countries.

In China, the STIRPAT model is widely recognized as an effective tool for analyzing the drivers of environmental impacts. For example, Zhang et al. (2012) applied the STIRPAT model to explore the influences of different drivers on carbon emissions from energy consumption in Anhui Province. Xiao et al. (2012) and Li et al. (2021) respectively studied the critical driving factors of the ecological footprints in Jiangsu Province and Shandong Province using the STIRPAT model. Zhang (2021) analyzed the influences of various factors on the carbon footprint of Xi'an and constructed a model to predict its future variations with the STIRPAT model. Cao and Fan (2022) used the STIRPAT model to study carbon emissions from the marine fisheries in 11 provinces of China. At the general debate of the 75th Session of the United Nations General Assembly in 2020, President Xi Jinping proclaimed that China would make efforts to peak CO_2 emissions before 2030 and accomplish carbon neutrality before 2060. Peak carbon emission and carbon neutrality have also been discussed recently by many researchers. For example, Yu (2022) suggested that Wuhan City should optimize the industry composition, adjust the structure of energy consumption, enhance the efficiency of energy use and reduce energy intensity to achieve its goals of peak carbon emission and carbon neutrality. Zhao et al. (2022) concluded that Zhejiang Province would achieve the goal of carbon peaking by 2030, and population, energy structure and real GDP per capita were the main factors affecting carbon emission reduction. Zhang and Du (2022) used the STIRPAT model to explore effective measures for reducing carbon emissions under the goal of "double carbon" in the Beijing-Tianjin-Hebei region. Gao et al. (2022) predicted whether the eastern margin ecotone of the Qinghai-Tibet Plateau would achieve the goal of "double carbon" under different scenarios with the help of the STIRPAT model.

The tourism sector is a global economic sector that produces pollution emissions, and consequently it negatively impacts the environment (Dogru et al., 2019). In this study, we deeply analyzed what drove the tourism environmental impacts expressed by tourism ecological footprint (TEF) in Mount Wutai. First, we conceived the extended STIRPAT model by the drivers of affluence, technology, population, ticket revenue and passenger turnover. Second, principal component regression was introduced to calculate the coefficients of the extended STIRPAT model. Third, we explained the elasticity coefficients of the drivers. Finally, we proposed several suggestions for reducing the TEF in Mount Wutai. This study provides a good example of the application of the STIRPAT model in tourism, and aims to give good recommendations to the policymakers responsible for sustainable tourism development.

2 Study area

Mount Wutai (38°50′11″–39°08′22″N, 113°24′51″–113°44′21″E) is located in Xinzhou City, Shanxi Province, China (Fig. 1) (Luo, 2021). It is one of the national 5A-class scenic spots in China, and is also famous around the world as a Buddhist holy place. It was listed as a world cultural heritage site in 2009. It has characteristics of the mountain landscape as well as the religious and architectural culture. It is home to ancient temples, and the stone carvings, murals, sculptures and calligraphy there are of great artistic value.

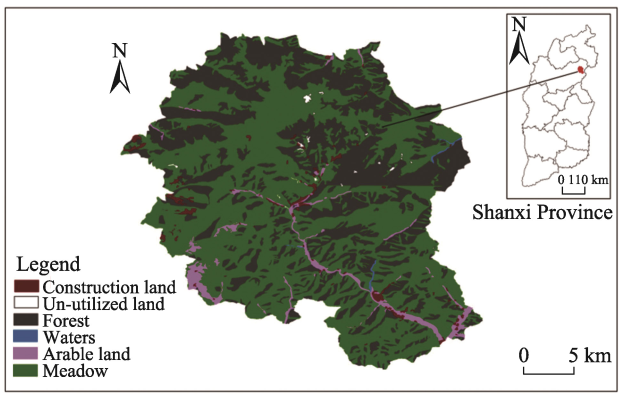

Fig. 1 The geographic location of Mount Wutai

3 Methods

3.1 Models

The extended STIRPAT model was used to track the drivers of the environmental impacts accurately and effectively. The environmental impacts of tourism were measured by TEF. Population was represented by tourist arrivals in Mount

Wutai (N). Affluence was represented by GDP per capita in Wutai County (GDP_w) and GDP per capita in China (GDP_c) in order to explore the influences of both the local and national economic levels. According to the environmental Kuznets curve (EKC), in the process of industrialization, environmental pollution presents an upward trend with the increase in per capita GDP at the early stage, but after the per capita GDP exceeds a certain threshold, environmental pollution shows a downward trend year by year, so overall it resembles an inverted U curve. Quadratic terms of GDP_w and GDP_c were introduced to the model to comprehensively examine whether the EKC appeared during the study period. Ticket revenue from domestic tourists in Mount Wutai (R) was included to test whether local tourism income affected the TEF. Technology was expressed by energy intensity, which referred to energy consumption per 10000 yuan GDP in China (T). National passenger turnover (PT) was added to test how national transportation development affected the TEF. Formula (1) was developed to determine how the TEF was impacted by each of these drivers.

$$TEF = \alpha_0 \times N^{\alpha_1} \times GDP_w^{\alpha_2} \times GDP_c^{\alpha_3} \times \left(GDP_w^2\right)^{\alpha_4} \times \left(GDP_c^2\right)^{\alpha_5} \times T^{\alpha_6} \times R^{\alpha_7} \times PT^{\alpha_8} \times \varepsilon \quad (1)$$

where TEF is the tourism ecological footprint in Mount Wutai, N is the tourist arrivals in Mount Wutai, GDP_w is the GDP per capita in Wutai County, GDP_c is the GDP per capita in China, T is energy intensity, R is ticket revenue from domestic tourists in Mount Wutai, PT is national passenger turnover, α_0, α_1,⋯, α_8 are parameters, and ε is a residual term.

In order to facilitate the calculation, the values of all variables were converted to their natural logarithms. Thus, formula (1) was modified to formula (2).

$$\ln TEF = \ln\alpha_0 + \alpha_1 \ln N + \alpha_2 \ln GDP_w + \alpha_3 \ln GDP_c + \alpha_4 \ln GDP_w^2 + \alpha_5 \ln GDP_c^2 + \alpha_6 \ln T + \alpha_7 \ln R + \alpha_8 \ln PT + \ln\varepsilon \quad (2)$$

The elasticity coefficients of GDP_w and GDP_c were respectively calculated by formulas (3) and (4).

$$EC_w = \alpha_2 + 2\alpha_4 \ln GDP_w \quad (3)$$

$$EC_c = \alpha_3 + 2\alpha_5 \ln GDP_c \quad (4)$$

where EC_w and EC_c in formulas (3) and (4) are respectively the elasticity coefficients of GDP_w and GDP_c.

3.2 Data

The TEF in Mount Wutai involves comprehensive consumption from food, accommodation, transportation, travel, shopping and entertainment. The calculation methods were described in detail by Luo (2021). Tourist arrivals and ticket revenue from domestic tourists in Mount Wutai were provided by the Wutai Mountain Scenic Area Management Committee. GDP per capita in China, energy intensity and national passenger turnover data were from the 2022 China Statistical Yearbook. Data for GDP per capita in Wutai County were from the 2006–2020 Shanxi Statistical Yearbook.

3.3 Statistical analysis

SPSS 20.0 was employed to conduct the data analysis. Spearman correlation analysis was used to determine whether the drivers were correlated with the TEF in Mount Wutai. KMO and Bartlett's test were employed to determine whether the variables were suitable for principal component analysis. Principal component regression was conducted by combining principal component analysis and regression analysis in order to estimate the extended STIRPAT model.

4 Results

4.1 Correlation analysis

The Spearman correlation analysis results (Table 1) showed that the TEF in Mount Wutai was positively correlated with the GDP per capita in China, the GDP per capita in Wutai County, ticket revenue from domestic tourists in Mount Wutai, national passenger turnover and tourist arrivals ($P < 0.01$). There was a significant negative correlation between the TEF in Mount Wutai and energy intensity ($P < 0.01$).

Table 1 The results of Spearman's correlation analysis for the *TEF* and its drivers

Drivers of *TEF*	*R*	*N*	GDP_c	*T*	*PT*	GDP_w
Correlation coefficients	0.825**	0.914**	0.875**	–0.875**	0.814**	0.875**
P	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
N	15	15	15	15	15	15

Note: ** represents a significant correlation at the 0.01 level.

4.2 TEF and its drivers

The TEF in Mount Wutai increased slowly from 27798.07 gha in 2005 to 29800.60 gha in 2014, and then it rose sharply after 2014 and grew to 67467.36 gha in 2019 (Fig. 2a) (Luo, 2021). Both the per capita GDP in Wutai County and the per capita GDP in China steadily grew from 2005 to 2019 (Fig. 2b, 2c). The per capita GDP in Wutai County was 2848 yuan in 2005 and 18966 yuan in 2019, while the per capita GDP in China was 14368 yuan in 2005 and 70078 yuan in 2019. The dynamic variations of tourist arrivals and ticket revenue were similar to the variations in the TEF (Fig. 2d, 2e). Tourist arrivals were 953600 persons in 2005, 1214131 persons in 2014 and 3186922 persons in 2019. The ticket revenue from domestic tourists in Mount Wutai was 80.32 million yuan in 2005, and it increased to 148.01 million yuan in 2014 and then to 410 million yuan in 2019. The national passenger turnover increased from 1746.67 billion person-km in 2005 to 3338.31 billion person-km in 2012, but then it decreased to 2757.17 billion person-km in 2013, and finally rose sharply to 3534.92 billion

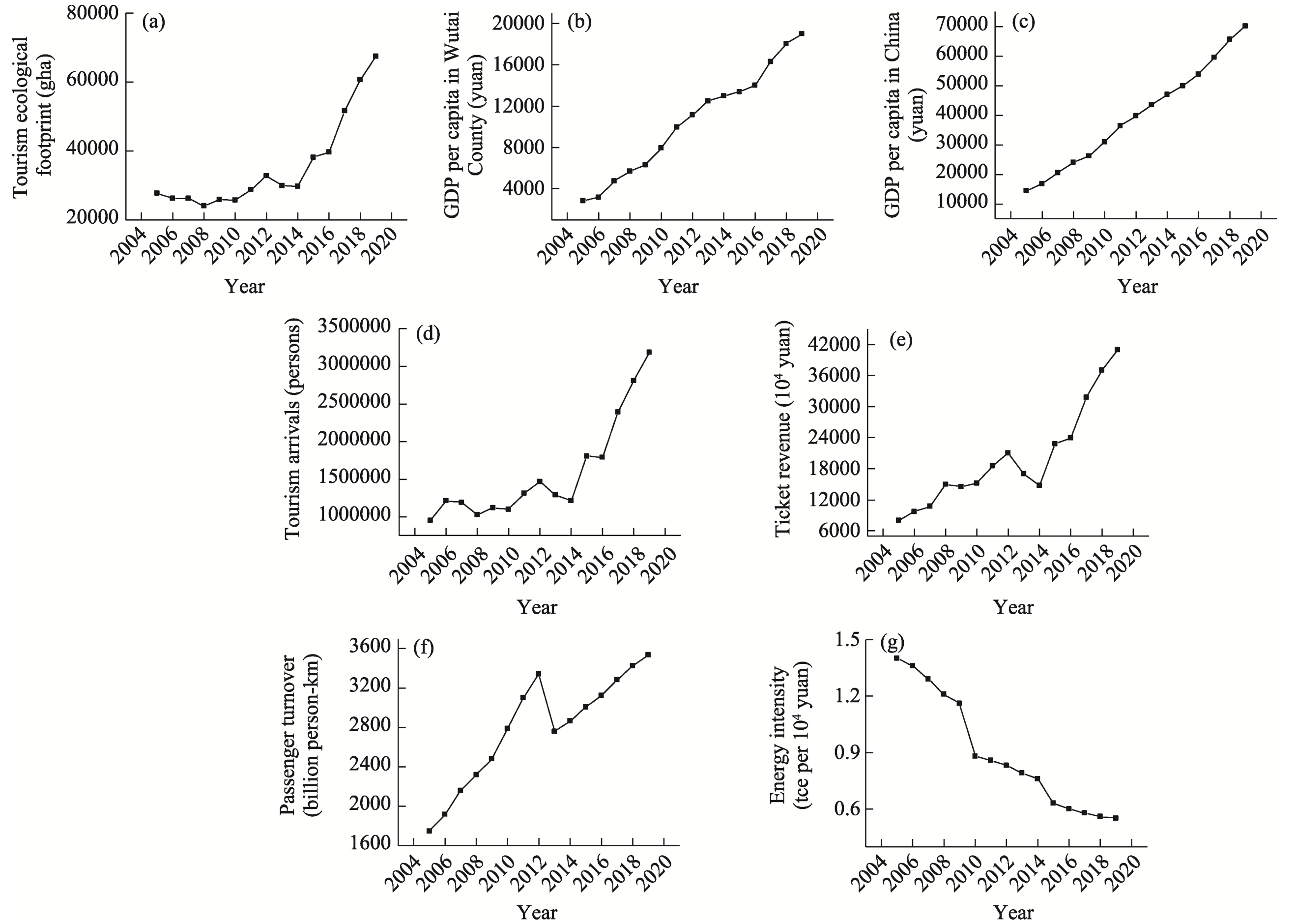

Fig. 2 Dynamic changes in the tourism ecological footprint and its drivers in Mount Wutai

person-km in 2019 (Fig. 2f). However, energy intensity showed a continuous downward trend from 2005 to 2019, declining from 1.40 tce (tons of standard coal equivalent) per 10000 yuan in 2005 to 0.55 tce per 10000 yuan in 2019 (Fig. 2g).

4.3 Principal component regression

The values of lnGDP_w, lnGDP_w^2, ln$N$, ln$T$, ln$R$, lnGDP_c, lnGDP_c^2 and lnPT were input into SPSS 20.0 to carry out the factor analysis. The results of KMO and Bartlett's test were presented in Table 2. The KMO value of 0.744 indicated that the variables had a relatively high degree of information overlap and were suitable for principal component analysis. The results of the Bartlett's test showed that the variables were correlated significantly (P < 0.05) and suitable for principal component analysis.

Table 2 KMO and Bartlett's test

Method	Statistic	Value
KMO test	Kaiser-Meyer-Olkin measure of sampling adequacy	0.744
Bartlett's test of sphericity	Approx. Chi-Square	414.069
	df	28
	P	< 0.05

The results of principal component analysis showed that the initial eigenvalue of the first principal component was 7.481 and its cumulative contribution rate reached 93.511%. The initial eigenvalues of the other principal components were less than 1. Therefore, extracting the first principal component fully met the requirements of the principal component analysis (Table 3). In the first principal component, the load values of lnGDP_w, lnGDP_w^2, ln$N$, ln$T$, ln$R$, lnGDP_c, lnGDP_c^2 and lnPT were respectively 0.986, 0.986, 0.867, –0.981, 0.965, 0.994, 0.994 and 0.956 (Table 4).

Table 3 Total variance explained

Component	Initial eigenvalue			Extraction sum of squared loadings		
	Total	Percentage of variance (%)	Cumulative contribution rate (%)	Total	Percentage of variance (%)	Cumulative contribution rate (%)
1	7.481	93.511	93.511	7.481	93.511	93.511
2	0.364	4.546	98.057			
3	0.105	1.313	99.371			
4	0.029	0.359	99.729			
5	0.020	0.245	99.974			
6	0.002	0.026	100.000			
7	0.000	0.000	100.000			
8	0.000	0.000	100.000			

Note: The extraction method was principal component analysis.

Table 4 Component matrix

Variable	Component 1
$\ln GDP_w$	0.986
$\ln GDP_w^2$	0.986
$\ln N$	0.867
$\ln T$	–0.981
$\ln R$	0.965
$\ln GDP_c$	0.994
$\ln GDP_c^2$	0.994
$\ln PT$	0.956

Note: The extraction method was principal component analysis, and one component was extracted.

The relationship between the principal component extracted and the standardized values of $\ln GDP_w$, $\ln GDP_w^2$, $\ln N$, $\ln T$, $\ln R$, $\ln GDP_c$, $\ln GDP_c^2$ and $\ln PT$ was expressed by formula (5).

$$Z = 0.360X_1 + 0.360X_2 + 0.317X_3 - 0.359X_4 + 0.353X_5 + 0.363X_6 + 0.363X_7 + 0.350X_8 \quad (5)$$

where Z denotes the principal component extracted; and X_1, through X_8 are the standardized values of $\ln GDP_w$, $\ln GDP_w^2$, $\ln N$, $\ln T$, $\ln R$, $\ln GDP_c$, $\ln GDP_c^2$ and $\ln PT$, respectively.

The significant linear regression relationship between the standardized value of $\ln TEF$ and the extracted principal component was described by formula (6) (R^2 = 0.703, P <0.001).

$$Y = 0.307 \times Z \quad (6)$$

where Y denotes the standardized value of $\ln TEF$, and Z is the extracted principal component.

By means of formula (7), the extended STIRPAT model was expressed by formula (8).

$$x' = \left(x - \overline{x}\right) / s \quad (7)$$

where x' is the standardized value, x is the original value, $\overline{x}$ is the mean, and s is the standard deviation.

$$\ln TEF = 0.060\ln GDP_w + 0.030\ln GDP_w^2 + 0.086\ln N - 0.108\ln T + 0.075\ln R + 0.074\ln GDP_c + 0.037\ln GDP_c^2 + 0.164\ln PT + 4.122 \quad (8)$$

4.4 Elasticity coefficients

The elasticity coefficients of N, R and PT were respectively 0.086, 0.075 and 0.164, which indicated that the TEF in Mount Wutai would increase by 0.086%, 0.075% and 0.164%, respectively, when those parameters increased by 1.00%. The elasticity coefficients of GDP_w, GDP_c, GDP_w^2 and GDP_c^2 were respectively 0.060, 0.074, 0.030 and 0.037. Therefore, the EKC did not exist and the local or national economic levels did not alleviate the TEF during the study period. The elasticity coefficients of GDP_w and GDP_c were not constant, and they increased with GDP_w and GDP_c (Table 5). The elasticity coefficient of T was –0.108, which indicated that the TEF in Mount Wutai would decrease by 0.108% when T increased by 1.00%.

Table 5 Elasticity coefficients of GDP_w and GDP_c

Year	Elasticity coefficient of GDP_w	Elasticity coefficient of GDP_c
2005	0.537	0.782
2006	0.544	0.794
2007	0.568	0.809
2008	0.579	0.821
2009	0.585	0.827
2010	0.599	0.839
2011	0.613	0.851
2012	0.619	0.858
2013	0.626	0.864
2014	0.628	0.870
2015	0.630	0.875
2016	0.633	0.880
2017	0.642	0.888
2018	0.648	0.895
2019	0.651	0.900

5 Discussion

5.1 The impact of affluence on TEF

Many studies have confirmed the existence of the EKC (Katircioğlu, 2014; Zaman et al., 2016). However, Xiao et al. (2012) calculated the elastic coefficients by taking the first partial derivative and did not detect the EKC between affluence and the ecological footprint in Jiangsu Province, China. Yu et al. (2017) reported that the Kuznets Curve did not appear between per capita GDP and the ecological footprint in Nanning City, China. York et al. (2003) found the elasticity coefficient of affluence increased with GDP per capita by using the extended STIRPAT model to analyze the energy footprint. Similarly, this study showed the EKC did not appear and affluence did not decrease the TEF in Mount Wutai from 2005 to 2019. The effective elastic coefficients in the extended STIRPAT model could reveal the relative importance of the drivers. The elasticity coefficient of GDP per capita in China was greater than that in Wutai County, indicating that the national economic development had a more significant impact than local economic development on the environmental pollution from tourism in Mount Wutai. The reason might be that most tourists visiting Mount Wutai came from different regions of the country, so the national economic development could more strongly boost the tourism in Mount Wutai.

5.2 The impact of population on TEF

Tourist arrivals require transportation, hotels, shops, restaurants and other tourist facilities, which contributes to environmental degradation (Ozturk et al., 2016; Adedoyin and Bekun, 2020). Solarin (2014) and Shakouri et al. (2017) found tourism arrivals enhanced CO_2 emissions. Based on the STIRPAT model, Wang and Liao (2019) showed that greater numbers of tourist arrivals were associated with more transportation carbon emissions. In this study, tourist arrivals drove environmental deterioration in Mount Wutai. More tourists consumed more resources. In addition, the tourists were mainly concentrated in the central area of Mount Wutai where most of the temples are located. Therefore, the growing number of tourists increased the environmental pressure especially in this area. In order to protect the environment, it is necessary to strictly implement the requirements of "limiting amount, reservation and peak shifting" and to optimize the spatial distribution of tourists in Mount Wutai by relying on information technologies such as big data, the Internet of Things (IoT), 5th-generation mobile communication technology (5G), artificial intelligence (AI) and cloud computing.

5.3 The impact of technology on TEF

Tourism has been a strategic pillar industry of China's economy. Travel has become a demand for people's aspiration for a better life in a moderately prosperous society, and an impetus for the optimization of economic structure. To realize the national aims of peak carbon emission and carbon neutrality, the Chinese government will continue to vigorously promote robust policies which save energy, protect the environment and encourage green, low-carbon and circular development. These policies undoubtedly depend on technical innovation. Technological innovation as well as environmental policies can reduce anthropogenic pollution (Alvarez-Herranz et al., 2017). Based on the extended STIRPAT model, it is reasonable to expect that friendly technology would effectively alleviate the adverse environmental consequences of tourism in Mount Wutai in the future (Paramati et al., 2017).

5.4 The impact of passenger turnover on TEF

Transportation is an indispensable ingredient of tourism, but it involves the use of different kinds of energy which further contributes to environment pollution. The contribution of the transportation ecological footprint to TEF ranged from 62.40% to 74.24% in Mount Wutai during the period of 2005–2019 (Luo, 2021). In this study, the largest elasticity coefficient in the extended STIRPAT model was for passenger turnover, which indicated that national passenger turnover was the most important driver of the TEF in Mount Wutai. Obviously, the rapid development of the transportation industry brought more environmental pollution even though it facilitated travel. Energy efficiency promotion and renewable energy usage in vehicles reduce pollution levels (Usman and Hammar, 2021). Therefore, increasing energy efficiency and the utilization of renewable energy in transportation would lead to the reduction of the TEF in Mount Wutai.

5.5 The impact of ticket revenue on TEF

The tourism industry in Mount Wutai boomed and ticket revenue from domestic tourists rose sharply from 2005 to 2019. However, the impact of ticket revenue was not large enough to keep tourism environmental pollution from getting worse. This finding was contrary to the results of some other studies. For example, Naradda et al. (2017) demonstrated that tourism receipts reduced CO_2 emissions in Sri Lanka; and Lee and Brahmasrene (2013) showed that tourism receipts reduced CO_2 emissions in the European Union countries. The policy implication is to allocate more funds to support infrastructure construction and advanced technology applications (Koçak and Ulucak, 2019), thereby promoting the environmental quality of Mount Wutai.

6 Conclusions

Based on statistical data and field survey data over the period 2005–2019, this study successfully established the extended STIRPAT model and used it to reveal how the TEF was statistically impacted by population, affluence, tourism income, technology, and national transportation development in Mount Wutai, China. The following conclusions were drawn from this analysis. Firstly, based on the elasticity coefficients from the extended STIRPAT model, 1% increases in tourist arrivals, ticket revenue and national passenger turnover would raise the TEF by 0.086%, 0.075% and 0.164% respectively. Secondly, a 1.00% increase in energy intensity would lead to reducing the TEF by 0.108%. Thirdly, the elasticity coefficients of the GDP per capita in China, the GDP per capita in Wutai County and their quadratic terms were positive. Therefore, the EKC did not appear, and both local and national economic growth increased pressure on environment in Mount Wutai rather than reducing it over the study period. In order to relieve the environmental pressure from tourism in Mount Wutai, three suggestions are given. Firstly, tourist arrivals should be limited strictly and the structure of the tourist distribution should be optimized rationally. Secondly, more funds should be invested in promoting environment quality. Thirdly, technological innovation should be advocated and implemented in tourism development.

References

Adedoyin F F, Bekun F V. 2020. Modelling the interaction between tourism, energy consumption, pollutant emissions and urbanization: Renewed evidence from panel VAR. *Environmental Science and Pollution Research*, 27: 38881–38900.

Alvarez-Herranz A, Balsalobre-Lorente D, Shahbaz M, et al. 2017. Energy innovation and renewable energy consumption in the correction of air pollution levels. *Energy Policy*, 105: 386–397.

Cao L, Fan L M. 2022. Research on driving factors of China's marine fisheries carbon emissions based on STIRPAT model. *Ocean Development and Management*, 39(5): 39–46. (in Chinese)

Dietz T, Rosa E A. 1994. Rethinking the environmental impacts of population, affluence and technology. *Human Ecology Review*, 1(2): 277–300.

Dietz T, Rosa E A, York R. 2007. Driving the human ecological footprint. *Frontiers in Ecology and the Environment*, 5(1): 13–18.

Dogru T, Isik C, Sirakaya-Turk E. 2019. The balance of trade and exchange rates: Theory and contemporary evidence from tourism. *Tourism Management*, 74: 12–23.

Gao F, Lv K X, Qiao Z, et al. 2022. Assessment and prediction of carbon neutrality in the eastern margin ecotone of Qinghai-Tibet Plateau. *Acta Ecologica Sinica*, 42(23): 9442–9455. (in Chinese)

Katircioğlu S T. 2014. Testing the tourism-induced EKC hypothesis: The case of Singapore. *Economic Modelling*, 41: 383–391.

Koçak E, Ulucak Z Ş. 2019. The effect of energy R&D expenditures on CO_2 emission reduction: Estimation of the STIRPAT model for OECD countries. *Environmental Science and Pollution Research*, 26: 14328–14338.

Lee J W, Brahmasrene T. 2013. Investigating the influence of tourism on economic growth and carbon emissions: Evidence from panel analysis of the European Union. *Tourism Management*, 38: 69–76.

Li Y, Wang Z C, Wei Y G. 2021. Pathways to progress sustainability: An accurate ecological footprint analysis and prediction for Shandong in China based on integration of STIRPAT model, PLS, and BPNN. *Environmental Science and Pollution Research*, 28: 54695–54718.

Luo S Z. 2021. Research on the dynamic change of tourism ecological footprint of Mount Wutai Scenic Spot. Beijing, China: China Meteorological Press: 159–161. (in Chinese)

Naradda G S K, Kuruppuge R H, Haq I U. 2017. Energy consumption, tourism development, and environmental degradation in Sri Lanka. *Energy Sources* (*Part B*): *Economics*, *Planning, and Policy*, 12(10): 910–916.

Ozturk I, Al-Mulali U, Saboori B. 2016. Investigating the environmental Kuznets curve hypothesis: The role of tourism and ecological footprint. *Environmental Science and Pollution Research*, 23: 1916–1928.

Paramati S R, Shahbaz M, Alam M S. 2017. Does tourism degrade environmental quality? A comparative study of Eastern and Western European Union. *Transportation Research Part D*, 50: 1–13.

Rosa E A, Dietz T. 1998. Climate change and society: Speculation, construction and scientific investigation. *International Sociology*, 13(4): 421–455.

Shakouri B, Khoshnevis Yazdi S, Ghorchebigi E. 2017. Does tourism development promote CO_2 emissions? *Anatolia*, 28(3): 444–452.

Solarin S A. 2014. Tourist arrivals and macroeconomic determinants of CO_2 emissions in Malaysia. *Anatolia*, 25(2): 228–241.

Solarin S A, Nathaniel S P, Bekun F V, et al. 2021. Towards achieving environmental sustainability: Environmental quality versus economic growth in a developing economy on ecological footprint via dynamic simulations of ARDL. *Environmental Science and Pollution Research*, 28: 17942–17959.

Usman M, Hammar N. 2021. Dynamic relationship between technological innovations, financial development, renewable energy, and ecological footprint: Fresh insights based on the STIRPAT model for Asia Pacific Economic Cooperation countries. *Environmental Science and Pollution Research*, 28: 15519–15536.

Wang Z F, Liao H L. 2019. Influencing factors and regional disparities of transportation carbon emissions in the Chang-Zhu-Tan urban agglomeration based on STIRPAT model. *Journal of Natural Science of Hunan Normal University*, 42(5): 1–9, 33. (in Chinese)

Xiao S S, Huang X J, Wu C D. 2012. A study on ecological footprint time series and its drivers of Jiangsu Province: Using the STIRPAT model and the PLS method. *Geography and Geo-Information Science*, 28(3): 76–82. (in Chinese)

York R, Rosa E A, Dietz T. 2003. STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics*, 46: 351–365.

Yu L F. 2022. Scenario analysis on carbon emission of Wuhan City based on STIRPAT model. *Journal of Hubei Polytechnic University*, 38(3): 1–6, 16. (in Chinese)

Yu P, Gao C, Hu B Q. 2017. Study on dynamic change of ecological footprints and driving factors in the process of urban ecological civilization construction—A case of Nanning City. *Industrial Safety and Environmental Protection*, 43(10): 11–15. (in Chinese)

Zaman K, Shahbaz M, Loganathan N, et al. 2016. Tourism development, energy consumption and Environmental Kuznets Curve: Trivariate analysis in the panel of developed and developing countries. *Tourism Management*, 54: 275–283.

Zhang L Q, Li R F, Chen S P, et al. 2012. Trend prediction and analysis of driving factors of carbon emissions from energy consumption during the period 1995–2009 in Anhui Province based on the STIRPAT model. *Resources Science*, 34(2): 316–327. (in Chinese)

Zhang P L, Du Q J. 2022. On influencing factors of carbon emissions in Beijing-Tianjin-Hebei region: Based on the extended STIRPAT model. *Scientific and Technological Management of Land and Resources*, 39(3): 14–23. (in Chinese)

Zhang W. 2021. Prediction and scenario analysis of carbon footprint in Xi'an based on the STIRPAT model. *Ecological Economy*, 37(4): 25–29. (in Chinese)

Zhao C, Song X C, Liu X Y, et al. 2022. Prediction and analysis of peak carbon emissions in Zhejiang Province based on STIRPAT model. *Ecological Economy*, 38(6): 29–34. (in Chinese)

基于 STIRPAT 模型追踪五台山旅游生态足迹驱动因子

罗淑政[1]，殷建树[2]，白海龙[3]，蔡富艳[4]

1. 忻州师范学院生物系，山西忻州 034000；
2. 五台山风景名胜区规划编制研究中心，山西忻州 034000；
3. 五台山风景名胜区文物与遗产保护局，山西忻州 034000；
4. 乌鲁木齐职业大学应用工程学院，乌鲁木齐 830002

摘　要：旅游业消费水平高，环境污染严重。随着五台山旅游业不断发展，环境压力持续增加。本研究旨在探讨 2005–2019 年五台山游客接待量、五台山国内游客门票收入、中国旅客周转量、能源强度、五台县人均 GDP 和中国人均 GDP 对五台山旅游生态足迹的影响。采用主成分回归构建了扩展的 STIRPAT（Stochastic Impacts by Regression on Population, Affluence and Technology）模型。结果表明:（1）五台山旅游生态足迹呈现增长趋势，2005 年为 27798.07 gha，到 2019 年则增至 67467.36 gha。（2）五台山游客接待量、五台山国内游客门票收入、中国旅客周转量、五台山人均 GDP、中国人均 GDP 均呈现增长趋势，而能源强度则呈现下降趋势。（3）扩展的 STIRPAT 模型表明五台山游客接待量、五台山国内游客门票收入和中国旅客周转量弹性系数分别为 0.086%、0.075%和 0.164%，说明它们每增加 1%，五台山旅游生态足迹分别增加 0.086%、0.075%和 0.164%；五台县人均 GDP 和中国人均 GDP 的弹性系数呈上升趋势，在研究期间环境库兹涅茨曲线没有出现，说明经济增长仍然没有减轻环境压力；能源强度弹性系数为–0.108%，说明它每增加 1%，五台山旅游生态足迹则降低 0.108%。因此，实施有效政策与技术创新能够显著降低五台山旅游生态足迹。

关键词：STIRPAT；旅游生态足迹；主成分回归；驱动因子