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# Beyond skyline and borders:
## Unraveling the evolution and drivers of tourism green development efficiency in the Beijing–Tianjin–Hebei urban agglomeration, China

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**Abstract:** Green development is a critical component of sustainable tourism, which prioritizes a comprehensive, ecologically-friendly, and people-oriented approach to development. This study presents a case study of the Beijing–Tianjin–Hebei (BTH) urban agglomeration from 2001 to 2021 to analyze the spatio-temporal evolution characteristics and influencing factors of tourism green development efficiency (TGDE). The study defines the concept of tourism green development and constructs an evaluation system, which is used to explore the internal differences and spatial patterns of TGDE within the urban agglomeration. The methodological approach includes the SBM–Undesirable model, kernel density estimation, Markov chain, and spatial gravity model. The findings indicate that the TGDE in the BTH urban agglomeration is generally favorable, displaying a temporal phase of "rising–declining–rising." However, the study observes lower TGDE in tourism node cities compared to tourism regional center cities and tourism core hub cities. The non-equilibrium degree of each region indicates significant spatio-temporal evolution patterns and internal differences among the three regions, with a spatially decreasing distribution of "core hub-regional center-node city." The TGDE in the urban agglomeration experienced an evolutionary trend of "first decreasing and then increasing" with apparent endogenous evolution characteristics. The linkage pattern of green development efficiency in the tourism industry between cities is relatively stable. Furthermore, neighboring cities generally exhibit a higher spatial connectivity strength of green development efficiency in the tourism industry compared to non-neighboring cities. Economic development level, industrial structure, and science and education level are identified as key factors that affect TGDE. However, the study finds that the factors influencing TGDE in tourism core hub cities, tourism regional center cities, and tourism node cities differ somewhat. Economic development level, industrial structure, science and education level, openness, and government regulation impact TGDE in tourism core hub cities and tourism regional center

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cities, while economic development level, industrial structure, and tourism resource endowment are the primary factors affecting TGDE in tourism node cities. The study provides policymakers and tourism practitioners with valuable insights into enhancing the green development of the tourism industry in the BTH urban agglomeration and other similar regions. Corresponding policy recommendations based on the results are proposed to improve the TGDE of the tourism industry in these regions, promote sustainable tourism development, improve the quality of life of local residents, and protect the ecological environment.

**Keywords: BTH urban agglomeration; tourism green development efficiency (TGDE); spatio-temporal evolution**

## 1 Introduction

Green development has emerged as a pivotal strategy in China's "new normal" economy, following the introduction of the five major development concepts, namely "Innovation, Coordination, Green, Openness, and Sharing". The 14th Five-Year Plan (2021–2025) and the 2035 Visionary Goals outline an ambitious agenda for promoting green development, with a focus on achieving ecological harmony by enhancing green and low-carbon development, improving environmental quality, enhancing ecosystem quality and stability, and improving resource utilization efficiency. Tourism recognized as a "green industry" due to its low energy consumption, low emissions, and low pollution, is an integral component of ecological civilization construction and the implementation of green development. The development of tourism green fosters the enhancement of ecological environment quality, the promotion of ecosystem stability, and the application of the "The verdant mountains and clear waters are akin to mountains of gold and silver." philosophy, with the aim of planning for high-quality tourism development in harmony with nature. However, despite the favorable economic, social, and ecological outcomes associated with tourism, it has the potential to yield negative environmental impacts. The World Tourism Organization and the United Nations Environment Programme report that tourism contributes to 5% of the total global carbon dioxide emissions and 5%–14% of global climate change caused by human factors. Moreover, unbalanced regional tourism development, over-exploitation of regional tourism resources, and ecological environment deterioration can lead to the loss and destruction of the ecological environment. Thus, achieving green development is crucial to facilitating sustainable and high-quality tourism development. Measuring the green development efficiency of the tourism industry, unveiling its spatio-temporal evolution pattern, and identifying influencing factors can bolster regional tourism collaboration, enhance tourism industry quality and efficiency, and provide a foundation for promoting high-quality tourism development.

## 2 Literature review

Green development is considered the successor of sustainable development, which has gained significant attention in the past few decades. The concept of green development was first proposed by economist Pearce, Markandya and Barbier (1989) in book "Blueprint for a Green Economy" as an extension of sustainable development. Since then, various associated concepts of green development, such as green economy, green industry, and green growth, have been introduced and studied in depth. In this regard, research on the construction of indicator systems, model construction and evaluation, spatial pattern and impact has provided substantial theoretical support for green development and policy formulation in tourism (Blake *et al.*, 2006; Ruiz, 2011; Law *et al.*, 2016; Paramati *et al.*, 2017; Assaf and Tsionas, 2018; Hao *et al.*, 2024). In the last two decades, China's tourism industry has undergone rapid and significant growth. However, the increase in tourism activities has led to environmental degradation and a decline in air quality, resulting in reduced tourism eco-efficiency (Dallia *et al.*, 2017; Eyuboglu and Uzar, 2019; Raihan and Tuspekova, 2022). Studies have argued that regions with a higher level of economic development have higher tourism eco-efficiency compared to regions with lower eco-efficiency. Additionally, technological innovation has emerged as a core driver in promoting regional tourism efficiency (Nguyen *et al.*, 2021; Sun *et al.*, 2022b). Transportation conditions and social civilization level are other key external factors that influence tourism efficiency improvement (Tang *et al.*, 2018). To tackle these challenges, tourism transportation companies have developed different green development strategies based on different transportation modes. For instance, the implementation of low-carbon transportation through traffic regulations and the promotion of walking tourism can help reduce tourism carbon emissions (Tong *et al.*, 2022). Moreover, the integrated development of industries can produce superimposed effects and achieve a shared win-win situation. Green finance has emerged as an essential factor in promoting tourism economic growth, especially in provinces with better economic and social conditions. As the tourism industry evolves, the energy efficiency and carbon efficiency of the tourism sector and industry are expected to increase (Moutinho *et al.*, 2015). The energy demand of the tourism industry stems from the development of transportation, food, accommodation, infrastructure, and tourism management, among other related sectors (Banerjee *et al.*, 2015; Kim *et al.*, 2021; Sun *et al.*, 2022b; Luo and Wang, 2023). However, the growth of these energy demands may result in reduced environmental quality (Katircioglu *et al.*, 2018; Lenzen *et al.*, 2018; Ali *et al.*, 2021). According to the United Nations World Tourism Organization, tourism accounts for more than 5% of total global emissions, whereas transportation accounts for 75% of tourism-related emissions, and accommodation accounts for 20% (IPCC, 2014). Studies have indicated a bidirectional causal relationship between $CO_2$, $NO_x$, $SO_2$, and $PM_{2.5}$ and tourism, and the increase in $CO_2$ emissions will negatively impact tourism development (Wang *et al.*, 2018; Gao and Zhang, 2021; Salahodjaev *et al.*, 2022). Therefore, the green development of tourism should not only focus on the construction of green transportation and accommodation, but also on policies and regulations, institutions, finance, technology, and culture (Pan *et al.*, 2018; Rico *et al.*, 2019; Ruan and Zhang, 2021; Xu and Deng, 2022; Nazneen *et al.*, 2023; Wang *et al.*, 2023). In conclusion, adopting sustainable and green practices in the tourism industry is crucial for environmental preservation and for achieving a sustainable and responsible tourism industry.

The fundamental of green development is to enhance the green development efficiency of the economy and industry, and the green development efficiency integrally reflects the coordinated development of a social-economic-environmental three-dimensional system. Tourism green development efficiency is based on the comprehensive consideration of resource and environmental consumption, reflecting the intrinsic link between the input and output of tourism activities, characterizing the reduction of tourism's impact on the ecological environment, maximizing the output of tourism benefits under environmental constraints, and the coordination of tourism economy and ecological environment (Liu *et al.*, 2017). It is an important criterion for measuring the green development of tourism, and is a comprehensive development efficiency that takes into account environmental factors and resource and environmental consumption, in the same vein as eco-efficiency (Li *et al.*, 2024). However, while eco-efficiency focuses on the proportional relationship between the economy and the environment and resources, green development efficiency places more emphasis on whether the region's economic development and social progress are fully decoupled from environmental protection (Peng *et al.*, 2017). Research related to tourism green productivity, on the other hand, focuses on tourism eco-efficiency (Ruan *et al.*, 2019; Shao *et al.*, 2021), tourism green innovation efficiency (Bi and Li, 2024), tourism resource green utilization efficiency etc (Lu *et al.*, 2023). Various methods such as spatial autocorrelation, kernel density, standard deviation ellipse, PVAR model, social network analysis method, gravity model, a center of the gravity model, etc. are used to portray the spatio-temporal evolution characteristics of tourism green development efficiency. Panel Tobit, VAR, and other regression models are used to reveal the influence mechanism of regional economic development level, industrial structure, technological innovation, tourism resource endowment, and other factors on tourism green development efficiency at different spatial scales (Kularatne *et al.*, 2018; Silva and Mattos, 2020; Hasanov *et al.*, 2023).

Regarding research regions, there is a clear focus on the green productivity of national-, provincial-, and prefecture-level industries. However, there is a lack of comprehensive research on the green development of urban agglomerations, metropolitan areas, economic zones, and other regions, which are important to consider given their significant impact on the economy and environment. Furthermore, in terms of research objects, the research has primarily focused on the green development level, efficiency evaluation, and spatial distribution of industrial, agricultural, manufacturing, and other related enterprises. This has led to the comprehensive evaluation of the green development efficiency of the tourism industry being overlooked, despite its status as the top industry for national happiness and its significant scale in the economy. In terms of research content and paradigm, there has been a strong focus on the theoretical discussion of green behavior of enterprises, environmental protection, and resource conservation within industries. However, little research has been conducted on the connotation, function, and mechanism of green development in the tourism industry. Additionally, the research on the green development efficiency of the tourism industry has not yet established a complete evaluation system. Important indicators, such as technological innovation and energy consumption, have not been integrated into the input-output process, making it difficult to truly and comprehensively understand the internal relationship between tourism development, the economy, society, and the natural environment.

The BTH Cooperative Development Strategy is a significant national strategy that promotes the harmonious sustainable development of ecological protection, resource development, and economic development. This strategy offers new opportunities and prospects for tourism development and plays a crucial role in promoting the coordinated development of tourism in this region. However, tourism development resources are not distributed evenly across the BTH urban agglomeration, resulting in low supply allocation efficiency, serious energy loss, and haze pollution, which hinder the green development of tourism in this area.

To address this, it is necessary to accelerate the integration, reorganization, and linkage of regional tourism resources and optimize the layout of the tourism industry to achieve the goal of maximizing tourism benefits while promoting green and synergistic tourism development in the BTH urban agglomeration. Therefore, this paper attempts to construct an evaluation system for the tourism green development efficiency of the BTH urban agglomeration by adopting a perspective of "efficiency measurement–evolutionary process–spatial pattern" and combining the SBM–Undesirable model to measure the tourism green development efficiency of this area. The study uses nonparametric kernel density estimation to reveal the spatio-temporal evolution characteristics of the tourism industry in the BTH urban agglomeration and the Markov chain and spatial gravity model to explore the influencing factors of the tourism green development efficiency. Through a panel data regression model, the study provides a practical basis for enhancing the green and high-quality development of tourism in the BTH urban agglomeration and the integrated development of tourism. Furthermore, the findings can provide a reference for the green development of tourism in other collaborative regions such as urban agglomerations, metropolitan areas, and economic zones.

## 3 Research framework, methods and data

### 3.1 Research framework

**3.1.1** Study the changes in tourism green development efficiency and reveal the trend of the evolution of the spatial pattern

The tourism spatial elements of urban agglomerations generally contain tourism nodes, tourism spatial connectors and tourism regions (Chen *et al.*, 2011). The polarization or diffusion of tourism spatial elements leads to different types of tourism space in urban agglomerations in terms of hierarchy, forming tourism core hub cities, tourism regional center cities and node cities (Cui *et al.*, 2022). The hierarchy of tourism space in urban agglomerations not only reflects the degree of concentration and decentralization of tourism activities among cities, but also has a significant impact on the green development efficiency of tourism and determines the spatial pattern of the green development efficiency of its tourism industry. With the rapid development of tourism, tourism exchanges and cooperation among regions have become increasingly frequent, thus making the green development level of tourism in neighboring regions have significant externalities on the local area, which is basically confirmed in the studies of the Yangtze River Economic Belt (Chen *et al.*, 2022), tourism-dependent cities (Sun *et al.*, 2024), and the Yellow River Basin (Zhang *et al.*, 2022) as the case sites. This paper studies the spatio-temporal evolution of the spatial pattern of tourism green development efficiency in the BTH urban agglomeration with the aim of analyzing the dynamics of tourism green development efficiency and dissecting the tourism green development gaps within the urban agglomeration.

**3.1.2** Multi-factor analysis of the causes of the spatio-temporal evolution of tourism green development efficiency in the Beijing–Tianjin–Hebei urban agglomeration

Resource and environmental heterogeneity, socio-economic contexts and increasing resource and environmental constraints have led to an increasingly densified and multilinear spatial network pattern of tourism green development efficiency. The diversity of the spatial pattern of green development efficiency of tourism in urban agglomerations leads to the multiplicity and complexity of factors affecting its spatio-temporal evolution.

In terms of scale factors, growth in economic scale increases the demand for factors of production and may also bring about undesired effects such as environmental pollution. The booming development of the regional economy and the tourism industry form a positive and positive interaction: economic growth provides a material basis for the tourism industry, and as the level of the economy rises, it supports the continued prosperity of the tourism industry by improving transportation, enhancing consumption capacity, optimizing the market and establishing public services. According to structural theory, economic growth benefits from capital accumulation, technological progress and labor force growth, as well as the optimization of industrial structure brought about by structural effects. The new growth theory places special emphasis on the endogenous role of technological progress, arguing that technological innovation is the key to achieving a win-win situation in terms of both economic growth and emission reduction.

The abundance of tourism resources determines the development potential of regional tourism, while an optimized development environment has a significant impact on the tourism economy and carbon emissions. New institutional economics states that an effective market system is crucial for the healthy development of the tourism economy. The green development of tourism relies on a flexible and effective market system, and the lack of a scientific system may lead to the over-exploitation of tourism resources and disorderly market competition, thus weakening the efficient output and sustainable development capacity of tourism. While an open environment is conducive to economic growth and efficiency, there is a need to guard against the "polluted paradise effect".

To summarize, this paper starts from the five dimensions of scale, structure, technology, resource endowment and development environment, and selects factors such as economic development level, industrial structure, level of science and education, tourism resource endowment, the degree of economic openness, and government regulation, to construct a multi-factor analytical framework for the efficiency of green development of tourism in the BTH urban agglomeration (Figure 1), with the aim of explaining the causes of its spatio-temporal evolution in a more systematic way.

### 3.2 Methodology

#### **3.2.1** Slack based model–undesirable model

The data envelopment analysis (DEA) model has limitations in measuring the efficiency of non-desired outputs and does not account for invalid DMU slack variables (Nurmatov *et al.*, 2021). However, in the tourism industry, non-desired outputs such as carbon emissions, wastewater, and gas are produced alongside economic and social desired outputs during the development process. To accurately measure the green development efficiency of tourism with non-desired outputs, this paper employs the SBM–Undesirable model (Slack-based model–Undesirable) proposed by Tone (2001). This model effectively addresses the invalid DMU slack variable and non-desired output issues. The formula is as follows:

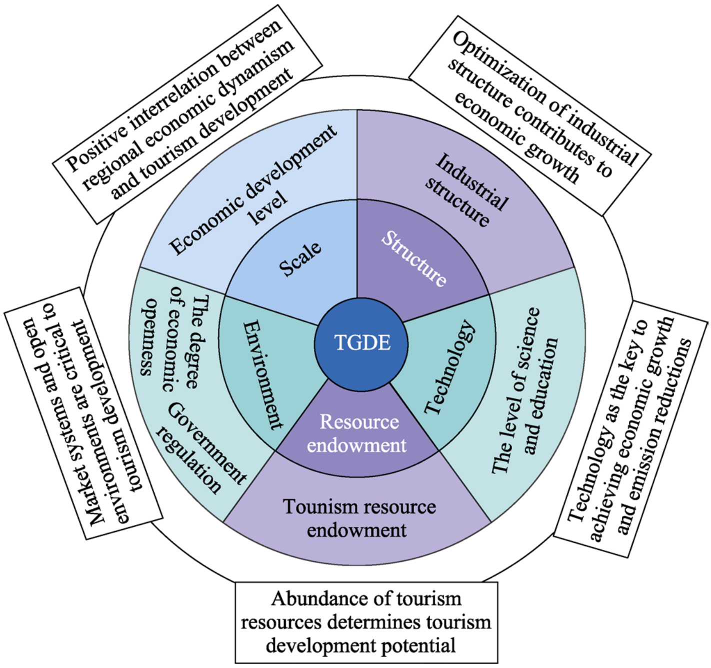


**Figure 1** The framework of research on the influencing factors of tourism green development efficiency

$$\rho = min\frac{1-\frac{1}{N}\sum_{n=1}^{N}S_n^x / x_{ix'}^i}{1+\frac{1}{M+1}\left(\sum_{m=1}^{N}S_m^y / y_{mp'}^{i'} + \sum_{i=1}^{t}S_i^b / b_{ip'}^t\right)} \quad (1)$$

$$\begin{aligned} & s.t.\sum_{t=1}^{T}\sum_{p=1}^{P}z_p^t x_{pn}^t + s_n^x = x_{np'}^i \quad (n=1,2,\dots,N) \\ & \sum_{t=1}^{T}\sum_{p=1}^{P}z_p^t y_{pm}^y - s_m^y = y_{mp'}^i \quad (m=1,2,\dots,M) \\ & \sum_{t=1}^{T}\sum_{p=1}^{P}z_p^t y_{pi}^y + s_i^b = b_{ip'}^i \quad (i=1,2,\dots,I) \\ & z_p^t \geqslant 0, s_n^x \geqslant 0, s_m^y \geqslant 0, s_i^b \geqslant 0 \quad (p=1,2\dots,P) \end{aligned} \quad (2)$$

where $\rho$ is the tourism efficiency value; $N$, $M$, and $I$ are the number of tourism inputs, desired outputs, and non-desired outputs, respectively, $n = [1, N]$, $m = [1, M]$, and $i = [1, I]$; $p$ is the decision unit; and $t$ is time; $s_n^x, s_m^y, s_i^b$ is slack in inputs, desired outputs and non-desired outputs; $x_{np'}^i$, $y_{mp'}^i$, and $b_{ip}^i$ is the amount of slack for the first $p'$ decision unit at $t'$ time based on the input, desired output, and undesired output; $z_p^t$ is the weight vector of the decision unit.

**3.2.2** Nonparametric kernel density estimation

Kernel density estimation (KDE) is used to estimate the smoothed empirical probability density function, which belongs to one of the nonparametric test methods and is a common spatial analysis technique to describe the spatially distributed intensity of geographic events, and is calculated as follows (Rosenblatt, 1956):

Let the density function of the random variable $f(x) = f(x_1, x_2, x_3)$, $x_1$, $x_2$, $x_n$ be independently distributed samples, and the probability density estimate of the random variable at the point $x_i$ is given by

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{n} K\left(\frac{Xi - \mathrm{x}}{h}\right) \tag{3}$$

where $N$ is the total number of 13 cities in Beijing, Tianjin, and Hebei; $K$ is the random kernel function; $h$ is the density estimation bandwidth, the larger the bandwidth, the smoother the density estimation and the larger the bias.

### 3.2.3 Markov chain

The Markov chain is a stochastic process in which the probability of transferring from one state to another in the $t$+1 period depends only on the current state, and not on the history (Yamaka *et al.*, 2023). By dividing the tourism green development efficiency into N states, we can obtain an N × N state transition probability matrix that shows the likelihood of moving from one state to another. The direction of the transition is determined by the changes in the type of tourism green development efficiency in urban agglomeration, which can be upward, downward, or remain constant over time.

### 3.2.4 Coefficient of variation (CV)

The coefficient of variation (CV) can be used to represent the relative fluctuation level of geographic data and is generally used to compare the degree of dispersion among different groups. The formula for calculating CV is as follows:

$$\mathrm{CV}=\sigma/\mu \tag{4}$$

where $\mu$ is the mean value of the data set, and $\sigma$ is the standard deviation of the data set. A larger CV value indicates a greater degree of differentiation in the tourism green development efficiency within the group, while a smaller CV value indicates a smaller degree of differentiation in the tourism green development efficiency within the group and a more balanced distribution.

### 3.2.5 Space gravity model

The gravity model, which is based on the principle of spatial interaction, can effectively measure the amount of spatial interaction between regions. It can also provide insight into the radiation capacity of the central region to its surrounding areas, as well as the degree of absorption of the diffusion effect of the central region by the neighboring territories. As a result, the gravity model has become a crucial tool for analyzing spatial interaction in the fields of new economic geography and regional economics (Rostami *et al.,* 2013). According to the "first law of geography," any element is spatially relevant, and tourism green development efficiency may be influenced by neighboring regions. Therefore, it is essential to consider spatial factors in the spatio-temporal evolution process of tourism green development efficiency. This study aims to examine the spatial linkage of tourism green development efficiency in the BTH urban agglomeration using the spatial gravity model. The model will assess and analyze tourism green development efficiency in a city within the agglomeration, demonstrating its impact on other cities' tourism green development efficiency and their acceptance of the city's radiation capability. It will also portray the strength and direction of the linkage of tourism economy between municipalities in the BTH urban agglomeration. The study will further refine the spatial linkage characteristics of tourism green development efficiency in the BTH urban agglomeration. The model equation is as follows:

$$R_{ij} = K \times \frac{g_i \times g_j}{d_{ij}^b} \tag{5}$$

where $g_i$ and $g_j$ denote the tourism economy of city $i$ and city $j$ respectively, $b$ is the attenuation factor of the linkage strength between municipalities $i$ and $j$, which usually takes the value of 2; $K$ is the gravitational constant, which usually takes the value of 1. $d_{ij}^b$ is the spatial distance between two cities, $R_{ij}$ indicates the spatial linkage strength of tourism economy between city $i$ and city $j$ in the BTH urban agglomeration, the greater the spatial linkage strength, the stronger the inter-municipal spatial linkage is characterized.

## 3.3 Indicators and data

### 3.3.1 Indicator system

Currently, there is a well-established international tourism total factor productivity measurement index system (Law *et al.*, 2017). Scholars generally exclude the land factor as it has little impact on tourism development (Cao *et al.*, 2012). Combining the connotation of green development in tourism, existing research results, and the accessibility of tourism data, we have constructed the green development efficiency input-output evaluation system for tourism, which is shown in Table 1. The comprehensive tourism green development efficiency input indicators mainly comprise labor, capital, and resources, with a focus on tourism labor, capital input, technological innovation, tourism basic hospitality level, and tourism energy consumption. The tourism output indicators include desired output and non-desired output, with tourism economic benefits and tourism passenger flow as desired output and environmental pollution as non-desired output.

**Table 1** Tourism green development efficiency evaluation index system

| Type | Elements | Indicator meaning |
|---|---|---|
| Input indicators | Capital investment | Measuring regional tourism inputs |
| | Labor input | Number of people employed in services in the region |
| | Tourism reception facilities | Measuring the capacity of the region to receive visitors |
| | Technical input | Measuring regional innovation capacity |
| | Energy consumption | Total energy consumption in the tourism industry |
| Output indicators | Economic benefits | Measuring the direct economic benefits generated by regional tourism |
| | Total tourist arrivals | Measuring the ability of the region to receive tourists |
| | Environmental pollution | Measuring the ecological output level of the tourism industry |

(1) Input indicators

① Capital investment: Capital input is a crucial indicator for measuring tourism efficiency, and fixed asset investment in tourism is an ideal indicator of capital input. When it comes to the BTH urban agglomeration, it is important to note that the amount of fixed asset investment is truly massive, which presents a challenge when attempting to distinguish tourism-related fixed asset investment from the overall figure. Notwithstanding, in light of the current impetus driving overall tourism development, it is a safe assertion that fixed asset investment plays a crucial and central role in fostering the expansion of the tourism industry. This study refers to the research result (Zhang *et al.*, 2022) and uses fixed capital stock as the capital input variable.

② Labor input: The role of labor input in tourism efficiency is mainly reflected in the accumulation of knowledge that human capital has. It promotes tourism efficiency by influencing the increase of productivity and the formation of production factors. The study draws on the research results of Liu and Zhang (2014), and uses the number of people employed in the tertiary industry to express labor input.

③ Tourism reception facilities: Tourism reception facilities refer to various tourist destination facilities for tourists to travel around the destination comfortably and enjoyably. The strengthening of tourism reception facilities can improve tourism service reception capacity and better meet tourists' accommodation, catering, and tourism needs. This paper draws on relevant studies (Wang *et al.*, 2022) and uses the number of star-rated hotels and travel agencies to characterize tourism reception facilities.

④ Technological innovation input: The transformation of tourism economic growth from factor input-driven to innovation-driven is the core of the new normal tourism economic growth momentum shift, and this innovation is mainly manifested as innovation in science and technology (Medina *et al.*, 2022). According to the China Tourism Talent Development Report (1949–2021) published by the China Tourism Research Institute, the majority of college graduates majoring in tourism and hospitality management did not directly enter the tourism industry, and senior management and innovation talents in the tourism industry often come from backgrounds in other disciplines, such as computer science and business. The element of technological innovation is the core element of tourism green development efficiency, and the number of higher education institutions is an important place and support for the training of tourism professionals, which can characterize the level of technological innovation investment in tourism (Jiang and Tang, 2018).

⑤ Resource consumption: Industries closely related to tourism, such as transportation, storage, and postal services, wholesale and retail trade, and accommodation and catering, are aggregated and accounted for to characterize tourism energy consumption (Liu and Tang, 2022).

(2) Output indicators

① Tourism revenue. Which is an indicator that measures the effectiveness of tourism activities in generating economic benefits. This is done by comparing consumption and labor occupation with the resulting benefits. It is worth noting that higher tourist satisfaction can lead to higher regional tourism income, which in turn significantly increases the tourism economic benefits. In this paper, we use total tourism revenue as a measure of the direct economic benefits generated by regional tourism activities (Fang and Huang, 2020).

② Total number of tourist trips. This indicator measures the social output of tourism. The total tourism trips are selected as the social output indicator since they are a direct output of tourism. The economic, social, and ecological effects of tourism are excluded from this indicator as they cannot be reasonably quantified (Fang and Huang, 2020).

③ Environmental pollution: Environmental pollution is a major issue associated with tourism, with carbon emissions from tourism and emissions of wastewater and waste gas being the primary culprits (Jia *et al.*, 2023). Carbon emissions from the tourism industry are estimated using the "bottom–up" method, which focuses on three segments: tourism transportation, tourism accommodation, and tourism activities (Bernardina *et al.*, 2022). Studies have indicated that the carbon emissions from tourism transportation, tourism accommodation, and tourism activities account for 67.72%, 29.92%, and 2.36% of the total carbon emissions from the tourism industry, respectively (Shi and Wu, 2011). The carbon emissions of tourism transportation are calculated using the method proposed by UNWTO (2008), which involves estimating the energy consumption and carbon emissions of passenger transport for each mode of transportation by multiplying the passenger turnover with the corresponding carbon emission factors. Since the proportion of water transport passenger turnover to the total national passenger turnover is low, only 0.23% in 2019, and fewer tourists choose to travel by water transport due to other factors such as convenient transportation, it can be presumed that the carbon emissions generated by water transport tourism traffic are relatively small. Therefore, the three primary indicators for measuring carbon emissions from tourism transportation are selected from railroads, roads, and airlines. The carbon emissions of tourism accommodation are calculated using the method proposed by Zhong *et al.* (2016), which involves estimating the carbon emissions of each bed per night by multiplying the number of beds in the region with the occupancy rate and the corresponding unit energy consumption value per bed per night. The carbon emissions of tourism activities are estimated by multiplying the number of tourists participating in a particular type of tourism activity in the region with the corresponding energy consumption parameters and summing the results. Currently, the individual accounting of indicators for tourist wastewater discharge, tourist gas emission, and tourist solid waste has not been conducted. Therefore, in reference to existing research, the ratio of total tourism revenue relative to GDP to conversion, i.e., tourism wastewater emissions = wastewater emissions × (total tourism revenue / GDP), and the same applies to tourism exhaust emissions (Liu and Song, 2018).

### **3.3.2** Overview of the study area

The BTH urban agglomeration is considered one of the top three urban agglomerations in China, encompassing Beijing, Tianjin, and Hebei province, which includes 11 prefecture-level cities of Shijiazhuang, Tangshan, Baoding, Qinhuangdao, Chengde, Cangzhou, Langfang, Zhangjiakou, Hengshui, Handan, and Xingtai. It is designated as "a world-class urban agglomeration with the capital at its core, a guiding area for overall regional cooperative development and reform, a new engine for innovation-driven economic growth, and a demonstration area for ecological restoration and environmental improvement." The land area of the BTH urban agglomeration covers 2.3% of China's total land area, with a GDP of 9.6 trillion RMB and a population of 113 million people in 2021 (China National Bureau of Statistics, 2022), making it one of the most dynamic, innovative, and population–absorbing regions in China. With the implementation of the BTH cooperative development strategy, efforts to deepen ecological and environmental protection joint control measures have been successful, resulting in effective green transformation and positive results in the battle for blue skies and environmental governance.

#### 3.3.3 Data

This paper focuses on Beijing, Tianjin, and 11 prefecture-level cities in Hebei province, and is based on available data from 2001 to 2021. The input and output indicators used in this study were obtained from the China Tourism Statistical Yearbook, China Energy Statistical Yearbook, China Transportation Statistical Yearbook, China Culture, Heritage and Tourism Statistical Yearbook, Beijing Statistical Yearbook, Tianjin Statistical Yearbook, Hebei Economic Yearbook (China National Bureau of Statistics, 2002–2022), and National Travel Agency Statistical Survey Report (China National Tourism Administration, 2002–2018; Ministry of Culture and Tourism of the People's Republic of China, 2019–2022), as well as the statistical bulletin of national economic and social development of Beijing, Tianjin, and Hebei cities for the same period. Tourism data for the Beijing, Tianjin, and Hebei urban agglomeration were collected from the local Bureau of Statistics, official government websites, and relevant websites of the Ministry of Education and the Ministry of Culture and Tourism. In cases where individual data points were missing, interpolation methods were used to supplement the missing period's data, ensuring the scientific accuracy and reliability of the calculations. Overall, the data used in this study is reliable, authoritative, and meets the requirements of the research.

## 4 Spatio-temporal pattern evolution of tourism green development efficiency in the Beijing–Tianjin–Hebei urban agglomeration

### 4.1 Temporal evolution characteristics of tourism green development efficiency

The study examines the changes in green development efficiency and the regional coefficient of variation of tourism in the BTH urban agglomeration from 2001 to 2021 (Table 2). The results reveal that the green development efficiency of tourism in the region has generally been at a good level during the study period. Specifically, the tourism green development efficiency value increased from 0.770 in 2001 to 1.127 in 2021, indicating a significant improvement of 46.36%. However, the efficiency exhibited considerable fluctuations during the study period. The corresponding regional coefficient of variation CV decreased from 0.615 to 0.121, suggesting that regional differences were reducing. Based on the changing characteristics of green development efficiency, the study divides the study period into three stages.

(1) In the first stage from 2001 to 2007, the region experienced a fluctuating declining trend in tourism green development efficiency. The tourism green development efficiency value declined from 0.770 in 2001 to 0.664 in 2007, representing a decrease of 13.77%. Meanwhile, regional differences expanded, with the CV index increasing from 0.615 to 0.693, indicating an increase of 12.68%. The primary reason for this trend was the increasing non-desired outputs, such as environmental pollution and carbon emissions, which were brought about by the rough development of tourism in the region. This led to a decrease in the efficiency of tourism green development in the BTH urban agglomeration. Moreover, the uncoordinated and insufficient regional economic development constrained the growth of

tourism green development efficiency. The significant differences in the scale of tourism economic development and environmental pollution index in Beijing, Tianjin, and Hebei province resulted in the gradual expansion of differences in tourism green efficiency of urban agglomerations and the emergence of prominent polarization phenomena.

(2) The research found that during this phase, the tourism industry experienced a fluctuating growth trend in terms of the tourism green development efficiency, and the regional difference coefficient decreased from 0.677 in 2008 to 0.330 in 2013, a decrease of 51.26%. Despite the financial crisis that significantly impacted the tourism market in 2008, the Olympic Games held in Beijing, Tianjin, and Hebei made the region a hot spot for Chinese and foreign tourists. This brought enormous income to the hotel industry, catering industry, and other tourism-related sectors in the region. Additionally, under the influence of the purpose of running the Green Olympics, tourism in Beijing, Tianjin, and Hebei began to pay more attention to the ecological environment. In 2009, the "Opinions of the State Council on Accelerating the Development of Tourism" was released, clarifying the positioning of tourism as "a strategic pillar industry of the national economy and a modern service industry that the people are more satisfied with." The document put forward the main tasks of tourism

**Table 2** Tourism green development efficiency and its coefficient of variation index in the Beijing–Tianjin–Hebei urban agglomeration (2001–2021)

| Year | Beijing | Tianjin | Shijiazhuang | Tangshan | Qinhuangdao | Handan | Xingtai | Baoding | Zhangjiakou | Chengde | Cangzhou | Langfang | Hengshui | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2001 | 1.190 | 1.185 | 1.066 | 1.034 | 1.484 | 1.076 | 0.386 | 1.188 | 0.302 | 0.474 | 0.296 | 0.111 | 0.225 | 0.615 |
| 2002 | 1.392 | 1.182 | 1.137 | 1.074 | 1.477 | 1.064 | 0.404 | 1.156 | 0.324 | 0.513 | 0.280 | 0.194 | 0.245 | 0.596 |
| 2003 | 1.283 | 1.228 | 1.058 | 1.060 | 1.469 | 1.009 | 0.376 | 1.103 | 0.326 | 0.447 | 0.263 | 0.223 | 0.264 | 0.592 |
| 2004 | 1.137 | 1.306 | 1.036 | 1.052 | 1.364 | 1.031 | 0.465 | 1.048 | 0.330 | 0.639 | 0.228 | 0.239 | 0.264 | 0.563 |
| 2005 | 1.351 | 1.362 | 1.010 | 1.045 | 1.340 | 1.048 | 1.002 | 1.015 | 0.333 | 1.004 | 0.192 | 0.268 | 0.202 | 0.519 |
| 2006 | 1.345 | 1.372 | 1.002 | 1.051 | 1.232 | 1.008 | 0.373 | 0.565 | 0.355 | 0.577 | 0.177 | 0.286 | 0.208 | 0.607 |
| 2007 | 1.351 | 1.359 | 0.352 | 1.069 | 1.213 | 0.416 | 0.344 | 1.002 | 0.357 | 0.568 | 0.164 | 0.264 | 0.178 | 0.693 |
| 2008 | 1.503 | 1.336 | 1.018 | 1.073 | 1.122 | 0.375 | 0.304 | 1.060 | 0.303 | 0.616 | 0.155 | 0.289 | 0.134 | 0.677 |
| 2009 | 1.515 | 1.207 | 1.020 | 1.116 | 1.213 | 0.559 | 0.461 | 1.098 | 0.398 | 1.046 | 0.271 | 1.009 | 0.293 | 0.475 |
| 2010 | 1.427 | 1.187 | 0.787 | 1.129 | 1.298 | 0.597 | 0.463 | 1.115 | 0.519 | 1.031 | 0.228 | 1.034 | 0.292 | 0.464 |
| 2011 | 1.391 | 1.210 | 1.011 | 1.080 | 1.239 | 0.482 | 0.387 | 1.094 | 0.543 | 1.037 | 1.200 | 1.002 | 0.292 | 0.478 |
| 2012 | 1.388 | 1.196 | 1.021 | 1.092 | 1.206 | 0.558 | 0.391 | 1.108 | 0.686 | 1.089 | 0.294 | 1.037 | 0.322 | 0.428 |
| 2013 | 1.401 | 1.238 | 1.080 | 1.063 | 1.171 | 1.075 | 0.484 | 1.100 | 1.028 | 1.148 | 0.373 | 1.015 | 0.463 | 0.330 |
| 2014 | 1.400 | 1.229 | 1.130 | 1.050 | 1.152 | 1.077 | 0.537 | 1.210 | 1.031 | 1.149 | 0.414 | 0.545 | 0.428 | 0.338 |
| 2015 | 1.435 | 1.220 | 1.173 | 1.033 | 1.164 | 1.112 | 0.512 | 1.229 | 1.038 | 1.171 | 0.303 | 0.496 | 0.475 | 0.386 |
| 2016 | 1.467 | 1.236 | 1.174 | 1.066 | 1.131 | 1.141 | 0.563 | 1.188 | 1.028 | 1.229 | 0.376 | 0.605 | 0.546 | 0.345 |
| 2017 | 1.431 | 1.214 | 1.200 | 1.098 | 1.153 | 1.192 | 0.575 | 1.187 | 1.019 | 1.198 | 0.408 | 0.716 | 0.610 | 0.313 |
| 2018 | 1.364 | 1.267 | 1.175 | 1.128 | 1.162 | 1.206 | 0.559 | 1.219 | 1.015 | 1.178 | 0.358 | 0.758 | 0.577 | 0.323 |
| 2019 | 1.409 | 1.255 | 1.173 | 1.163 | 1.177 | 1.186 | 0.560 | 1.189 | 1.034 | 1.151 | 0.504 | 0.727 | 0.566 | 0.303 |
| 2020 | 1.305 | 1.311 | 1.189 | 1.244 | 1.211 | 1.211 | 1.097 | 1.222 | 0.804 | 1.156 | 1.039 | 0.772 | 1.035 | 0.153 |
| 2021 | 1.347 | 1.293 | 1.141 | 1.203 | 1.147 | 1.227 | 1.037 | 1.208 | 1.078 | 1.086 | 1.027 | 0.819 | 1.036 | 0.121 |
| Average | 1.382 | 1.257 | 1.043 | 1.092 | 1.244 | 0.936 | 0.537 | 1.110 | 0.660 | 0.929 | 0.359 | 0.591 | 0.412 | 0.445 |

development in recent years, advocating for health tourism, civilized tourism, and tourism green. The three regions of Beijing, Tianjin, and Hebei actively introduced corresponding policies and measures to promote the healthy and sustainable development of tourism, thereby increasing the level of tourism green development efficiency.

(3) The third stage is the adjustment and transformation period from 2014 to 2021. During the period, the tourism green development efficiency increased from 0.950 in 2014 to 1.127 in 2021, while the regional difference coefficient decreased from 0.338 to 0.121. This was due to several factors. On the one hand, the national policy of advocating green development, especially the introduction of the green development concept in 2015, provided direction for the transformation of the tourism industry in the region. The release of the National Eco-tourism Development Plan (2016–2025) in 2016 also played a vital role in laying a good ecological foundation for the tourism development of the BTH urban agglomeration. On the other hand, the state issued several documents on energy conservation and emission reduction in tourism, including "guidance on further promoting energy conservation and emission reduction in the tourism industry" and "30 articles on energy conservation and emission reduction in A-class scenic spots". These policies were taken seriously by the tourism management departments of the BTH urban agglomeration and various tourism enterprises and institutions. They began to attach great importance to the work of energy conservation and emission reduction as an important step towards achieving the transformation and upgrading of tourism to promote sustainable development. Further, the penetration of internet technology and changes in the technical paradigm of tourism also contributed to the improvement of green development efficiency. Carbon emissions and energy consumption of tourism have been continuously reduced. As a result, the efficiency of green development of tourism in BTH urban agglomeration showed a steady trend of improvement after a short period of adjustment and decline, and the gap between the regions gradually narrowed.

### 4.2 Spatial evolution characteristics of tourism green development efficiency

To depict the spatial evolution of tourism green development efficiency in the BTH urban agglomeration at a regional level, this study refers to relevant literature (Cui *et al.*, 2022) and divides the region into three hierarchical areas: tourism core hub cities, tourism regional center cities, and tourism node cities. The tourism core hub cities are locations with concentrated tourism resources, convenient transportation, frequent business, and a significant position in tourism economic activities in the BTH urban agglomeration, with tourism revenue accounting for more than 20% of the total tourism revenue. The tourism regional center cities are areas with diverse tourism resources, more accessible transportation, and a second position in tourism economic activities, with tourism revenue accounting for more than 1% of the total tourism revenue in Beijing, Tianjin, and Hebei. Finally, tourism node cities refer to regions with some tourism resources, more convenient transportation, and a certain tourism carrying capacity, which has a specific status in the tourism economic activities in the BTH urban agglomeration.

Based on the above criteria, Beijing and Tianjin are the core tourism hub cities, Shijiazhuang, Baoding, and Qinhuangdao are the tourism regional center cities, and all other cities are considered tourism node cities. The study's results (Table 3) demonstrate that the green development efficiency of tourism in Beijing, Tianjin, and Hebei province from 2001 to

**Table 3** Tourism green development efficiency and its coefficient of variation index in the Beijing–Tianjin–Hebei urban agglomeration (2001–2021)

| Year | Tourism green development efficiency | | | CV index | | |
|---|---|---|---|---|---|---|
| | Core tourism hub cities | Tourism regional center cities | Tourism node cities | Core tourism hub cities | Tourism regional center cities | Tourism node cities |
| 2001 | 1.187 | 1.246 | 0.498 | 0.003 | 0.289 | 0.998 |
| 2002 | 1.287 | 1.257 | 0.512 | 0.115 | 0.280 | 0.916 |
| 2003 | 1.233 | 1.210 | 0.496 | 0.005 | 0.292 | 0.921 |
| 2004 | 1.340 | 1.149 | 0.531 | 0.036 | 0.254 | 0.795 |
| 2005 | 1.357 | 1.122 | 0.637 | 0.006 | 0.116 | 0.690 |
| 2006 | 1.359 | 0.933 | 0.505 | 0.014 | 0.352 | 0.756 |
| 2007 | 1.355 | 0.856 | 0.420 | 0.004 | 0.471 | 0.932 |
| 2008 | 1.419 | 1.067 | 0.406 | 0.083 | 0.355 | 0.976 |
| 2009 | 1.361 | 1.110 | 0.644 | 0.160 | 0.287 | 0.591 |
| 2010 | 1.307 | 1.067 | 0.662 | 0.129 | 0.312 | 0.591 |
| 2011 | 1.300 | 1.115 | 0.628 | 0.099 | 0.319 | 0.621 |
| 2012 | 1.292 | 1.112 | 0.684 | 0.105 | 0.302 | 0.535 |
| 2013 | 1.319 | 1.117 | 0.831 | 0.087 | 0.227 | 0.381 |
| 2014 | 1.314 | 1.164 | 0.779 | 0.092 | 0.211 | 0.426 |
| 2015 | 1.328 | 1.180 | 0.768 | 0.115 | 0.224 | 0.468 |
| 2016 | 1.352 | 1.164 | 0.819 | 0.121 | 0.206 | 0.396 |
| 2017 | 1.322 | 1.180 | 0.852 | 0.116 | 0.207 | 0.358 |
| 2018 | 1.316 | 1.186 | 0.847 | 0.052 | 0.215 | 0.381 |
| 2019 | 1.332 | 1.180 | 0.861 | 0.082 | 0.214 | 0.346 |
| 2020 | 1.308 | 1.207 | 1.045 | 0.003 | 0.043 | 0.163 |
| 2021 | 1.320 | 1.165 | 1.064 | 0.029 | 0.060 | 0.114 |
| Average | 1.319 | 1.133 | 0.689 | 0.069 | 0.249 | 0.588 |

2021 shows an inside-out decreasing distribution pattern of "core hub-regional center-node city," with average values of 1.319, 1.133, and 0.689 in the three regions, respectively. The spatio-temporal evolution patterns and internal differences of the three regions are also significant. Specifically, the tourism green development efficiency of core tourism hub cities fluctuates and increases from 1.187 in 2001 to 1.319 in 2021. The tourism green development efficiency of regional center cities goes through a decreasing phase from 2001 to 2007, followed by a gradual increase to 1.165 in 2021. The tourism green development efficiency of tourism node cities has a "wave-like" upward pattern, increasing from 0.498 in 2001 to 1.064 in 2021, with an increase of 53.20% and a larger increase in tourism green development efficiency. Regarding the degree of non-equilibrium, the BTH tourism node cities (0.588) exhibit the highest level, followed by the tourism regional center cities (0.249), and tourism core hub cities (0.069). The degree of non-equilibrium of each region has converged; tourism core hub cities experience less change, whereas tourism regional center cities and tourism node cities show a "wave" decreasing pattern (Figure 2). The BTH tourism hub cities are leading areas of tourism green development, characterized by rich tourism resources, high levels of economic development, technological innovation, perfect tourism infrastructure, and excellent tourism service reception levels and service quality. However, they also face several issues such as big city diseases, non-decoupling of tourism activities and energy consumption, and ecological environment. Tourism regional center cities have relatively balanced development, with many high-quality tourism resources, and a maintained good level of tourism green development efficiency, driven by the continuous improvement of tourism policy systems, growth of national tourism demand, and construction of ecological civilization. On the other hand, tourism node cities have good resource advantages, but face challenges such as scattered distribution of attractions, low levels of urbanization, weak technical innovation, and low levels of economic development, and thus maintain a low to medium level of tourism economic benefits and tourism green development efficiency.

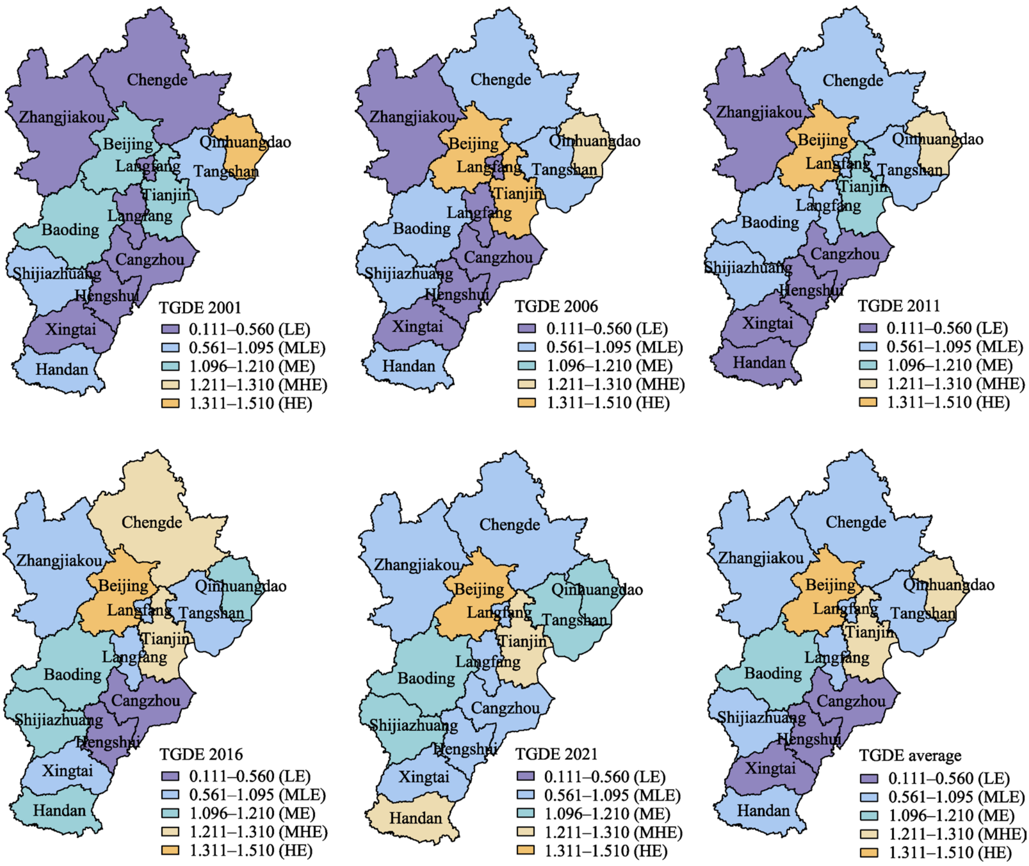


**Figure 2** Spatial characteristics of tourism green development efficiency in the Beijing–Tianjin–Hebei urban agglomeration (2001–2021)

Since 2001, 2006, 2011, 2016 and 2021 represent the starting years of the 10th, 11th, 12th, 13th, and 14th Five-Year Plans respectively, with five-time periods selected to examine the green development of tourism in the BTH urban agglomeration. Specifically, this study aims to visualize the spatial pattern of tourism green development efficiency in the BTH urban agglomeration during these five periods, which correspond to the 13th and 14th Five–Year Plans. The findings indicate that the green development efficiency of tourism in the BTH from 2001 to 2021 exhibits regional spatial divergence, with significant differences observed between different areas. Recently, under the influence of various factors including the leadership of the BTH cooperative development strategy, rising tourism market demand, and the growing emphasis on sustainable development, the regional industrial structure and development mode have been optimized, resulting in improved levels of tourism development and an increasing trend in tourism green development efficiency.

### 4.3 Dynamic evolution characteristics of tourism green development efficiency

#### 4.3.1 Results of kernel density estimation

To further investigate the evolution characteristics of tourism green development efficiency in the BTH urban agglomeration from 2001 to 2021, the Kernel density estimation method is used to analyze its dynamic evolution characteristics. From Figure 3a, it can be seen that the main peak of tourism green development efficiency in the BTH urban agglomeration shows an overall "leftward and then rightward shift", indicating that the level of tourism green development efficiency in the urban agglomeration has experienced an evolutionary trend of "first decreasing and then increasing", and this feature is consistent with the trend of the average value of tourism green development efficiency in the BTH urban agglomeration in the previous paper. This feature is consistent with the trend of the average value of green development efficiency of tourism in the BTH urban agglomeration.

From 2001 to 2021, the trend of bimodal to unimodal evolution is shown, with the efficiency values of the first wave clustering around 0.5 and the second wave clustering around 1.0; the peak of the first wave is lower than that of the second wave, and the distance between the primary and secondary waves is decreasing year by year, indicating that the polarization of tourism green development efficiency in the BTH urban agglomeration is weakening. Especially during 2019–2021, the single-peak phenomenon is obvious, and the distribution extension has contraction characteristics, which means that the spatial gap of tourism green development efficiency in the BTH urban agglomeration is gradually narrowing, the development level of high-efficiency areas still maintains an upward trend, and the balance between tourism economy, tourism ecology, and tourism social development in the BTH is gradually increasing. From the sub-regional point of view, the main peak position of Figure 3b does not show obvious changes, its regional tourism green development efficiency level is relatively stable, the degree of a synergy of regional urban tourism green development efficiency is high, and the phenomenon of polarization is not significant. The main peak position of Figure 3c shows an evolutionary trend of a right shift in general, and the right shift of tourism node cities has increased in recent years, indicating that the tourism green development efficiency of tourism node cities has an upward trend during the study period, and the efficiency enhancement speed is obvious.

#### 4.3.2 Trends in spatial and temporal shifts

The kernel density estimation results reveal the dynamic evolution characteristics of tourism green development efficiency in the BTH urban agglomeration, but they fail to reflect the future development trend of tourism green development efficiency levels. Therefore, Markov chains are used to further explore internal mobility as well as the stability of tourism green development efficiency in the BTH urban agglomeration. Firstly, drawing from the studies of Lu and Chen (2016), and following the suggestion of Le (2004) to use a similar number of observations for each type, we have classified the green development efficiency of the tourism industry in 13 cities within the BTH urban agglomeration. Based on the

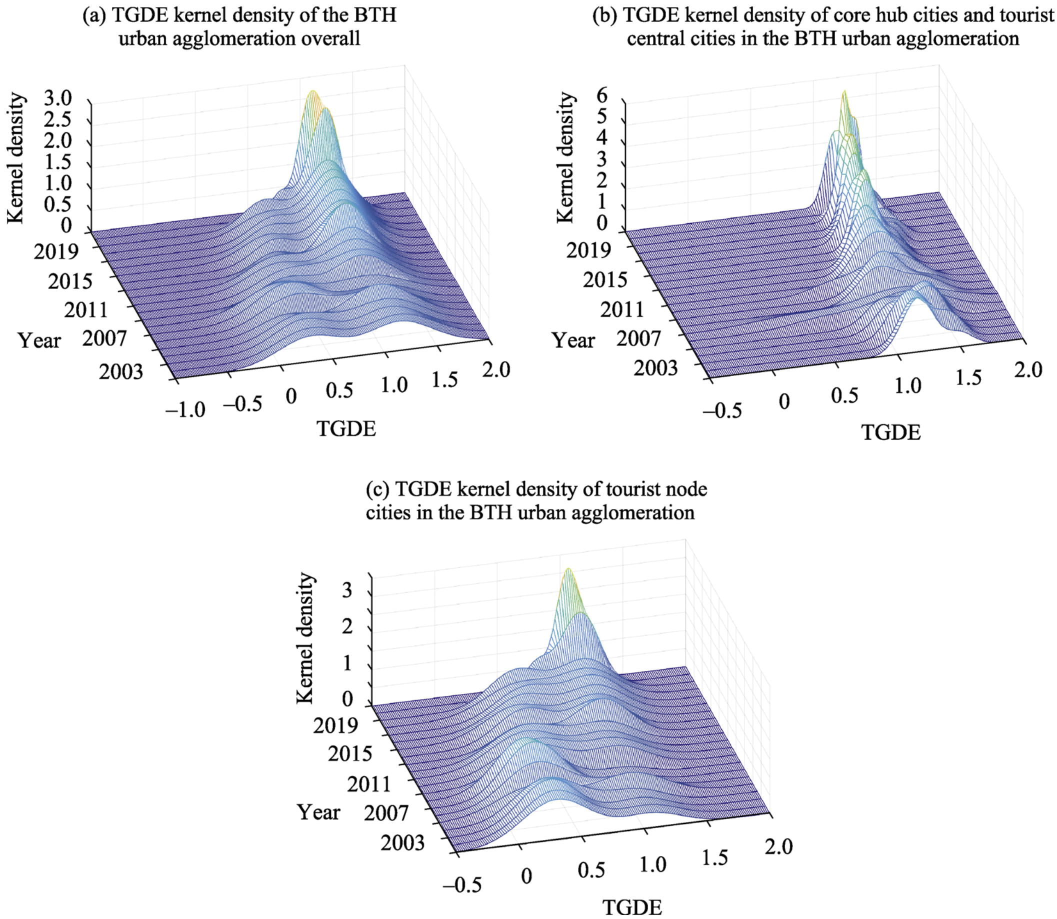


**Figure 3** The kernel density dynamic evolution of tourism green development efficiency in the Beijing–Tianjin–Hebei urban agglomeration (2001–2021)

calculated green development efficiency values, we have divided them into five continuous intervals using 30%, 60%, 80%, and 90% as breakpoints: (0.111, 0.560), (0.561, 1.095), (1.096, 1.210), (1.211, 1.310), and (1.311, 1.510), represent five levels of "low efficiency, medium-low efficiency, medium efficiency, medium-high efficiency, and high efficiency", respectively. A higher value indicates a higher green development efficiency of the tourism industry. Secondly, the study period is divided into four stages: 2001–2006, 2006–2011, 2011–2016, and 2016–2021. Finally, the Markov chain analysis is applied to obtain the transfer matrix of tourism green development efficiency from 2001–2021, shown in Table 4. The elements on the diagonal line of the 5×5 matrix represent the probability that the tourism green development efficiency level of each region does not undergo a type shift, indicating the stability of the tourism green development efficiency. The elements on the non–diagonal line show the probability that the type of tourism development efficiency level of each region undergoes an upward or downward shift.

The findings indicate that: (1) The level of green development efficiency in the tourism industry of the BTH urban agglomeration is relatively stable and maintains its original state to a certain degree. The values on the main diagonal are mostly greater than those on the off–diagonal, and types 1 and 5 have a probability of 85% and 82.1%, respectively, of

**Table 4** Markov chain probability transfer matrix for tourism green development efficiency in the Beijing–Tianjin–Hebei urban agglomeration (2001–2021)

| Type | 2001–2021 | | | | | 2001–2006 | | | | | 2006–2011 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LE | MLE | ME | MHE | HE | LE | MLE | ME | MHE | HE | LE | MLE | ME | MHE | HE |
| LE | 0.850 | 0.137 | 0.013 | 0.000 | 0.000 | 0.926 | 0.074 | 0.000 | 0.000 | 0.000 | 0.885 | 0.115 | 0.000 | 0.000 | 0.000 |
| MLE | 0.080 | 0.822 | 0.086 | 0.012 | 0.000 | 0.047 | 0.857 | 0.048 | 0.048 | 0.000 | 0.143 | 0.762 | 0.095 | 0.000 | 0.000 |
| ME | 0.000 | 0.102 | 0.673 | 0.204 | 0.020 | 0.000 | 0.400 | 0.400 | 0.200 | 0.000 | 0.000 | 0.167 | 0.500 | 0.333 | 0.000 |
| MHE | 0.000 | 0.000 | 0.375 | 0.458 | 0.167 | 0.000 | 0.000 | 0.360 | 0.473 | 0.167 | 0.000 | 0.000 | 0.250 | 0.750 | 0.000 |
| HE | 0.000 | 0.000 | 0.036 | 0.143 | 0.821 | 0.000 | 0.000 | 0.000 | 0.200 | 0.800 | 0.000 | 0.000 | 0.125 | 0.000 | 0.875 |

| Type | 2011–2016 | | | | | 2016–2021 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | LE | MLE | ME | MHE | HE | LE | MLE | ME | MHE | HE |
| LE | 0.800 | 0.200 | 0.000 | 0.000 | 0.000 | 0.571 | 0.286 | 0.143 | 0.000 | 0.000 |
| MLE | 0.053 | 0.789 | 0.158 | 0.000 | 0.000 | 0.056 | 0.889 | 0.055 | 0.000 | 0.000 |
| ME | 0.000 | 0.000 | 0.786 | 0.214 | 0.000 | 0.000 | 0.083 | 0.709 | 0.208 | 0.000 |
| MHE | 0.000 | 0.000 | 0.429 | 0.571 | 0.000 | 0.000 | 0.000 | 0.454 | 0.364 | 0.182 |
| HE | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.400 | 0.600 |

Note: LE, MLE, ME, MHE, and HE represent low efficiency, medium-low efficiency, medium efficiency, medium-high efficiency, and high efficiency, respectively.

maintaining their original status, suggesting greater stability. However, the minimum probability on the diagonal is 45.8%, implying that the tourism green development efficiency of a specific type in the BTH urban agglomeration may have a probability of over 50% of transferring to other types in the following year, which could lead to an "unstable" level of tourism green development efficiency. (2) The level of green development efficiency in the tourism industry of the BTH urban agglomeration may undergo level transfer, but it is challenging to achieve cross–level transfer. The transfer probability between different development levels is not high, as indicated by the maximum value of 0.454 on the off–diagonal, which is only 45.4% of the maximum probability of 1 on the diagonal. The transfer between different green development efficiency levels only represents an upward or downward stage, and it is difficult to make a significant leap from low efficiency to high efficiency. In other words, the green development efficiency of the tourism industry is a gradual process, and it is challenging to achieve rapid progress in a short time. (3) The probability of transferring green development efficiency values at different stages varies. The probability of maintaining the original level of green development efficiency during the entire survey period is at least 67.3%. It is 40.0% from 2001 to 2006, 50.0% from 2006 to 2011, 78.6% from 2011 to 2016, and 70.9% from 2016 to 2021. That is, there is a "club convergence" phenomenon in the green development efficiency of the tourism industry in the BTH urban agglomeration, with obvious endogenous evolution characteristics. (4) The probability of low-efficiency areas maintaining their original status quo between 2001 and 2021 is 85.0%, while the probability of maintaining a relatively low efficiency level is 82.2%, and the probability of improvement is 9.8%. This indicates that it is difficult to improve the efficiency of low-efficiency areas in the short term. The probability of maintaining the same efficiency level for medium-efficiency areas is 67.3%, while the probability of moving downward is 10.2% and the probability of moving upward is 22.%. The probability of maintaining the same efficiency level for high-efficiency areas is 82.1%, while the risk of decreasing efficiency is 17.9%. Therefore, we should continuously improve the green development efficiency level of the tourism industry in moderate and high-efficiency areas and promote entry into higher-level club ranks.

As tourism continues to rapidly develop in each region, the exchange links between regions become closer, and the level of tourism green development in neighboring regions will increasingly impact the local area. Therefore, it is crucial to considerate spatial factors and construct a spatial gravity model to depict the spatial linkage structure of tourism green development efficiency among cities in the BTH urban agglomeration for the years 2001, 2006, 2011, 2016, and 2021 (Figure 4).

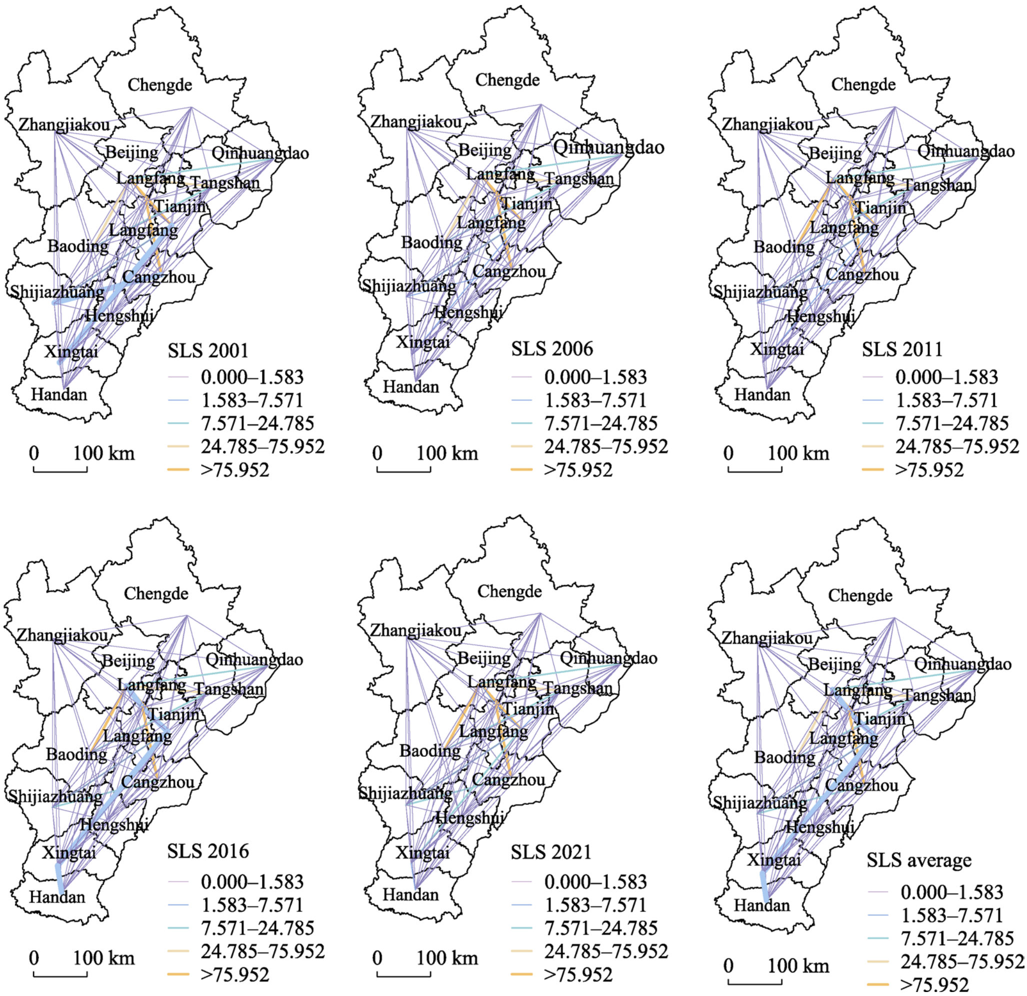


**Figure 4** The spatial linkage strength (SLS) in the Beijing–Tianjin–Hebei urban agglomeration (2001–2021)

Figure 4 shows that the tourism economy spatial linkage in the BTH urban agglomeration has remained relatively stable from 2001 to 2021. The spatial linkage among neighboring cities in the region is generally higher than that among non-neighboring cities. Moreover, the spatial linkage strength weakens as the distance between two regions increases, which is consistent with the law of distance decay in geography. The core hubs of the BTH urban agglomeration and the tourism regional center cities have a stronger connection to tourism green development efficiency, while tourism node cities are relatively less connected to the core hubs and tourism regional center cities. This suggests that the cross-regional flow of production factors is somewhat restricted, highlighting the importance of breaking down city barriers, seeking development with synergy, and promoting win-win situations. A comparison of the spatial linkage intensity of tourism economy in the BTH urban agglomeration from 2001 to 2021 reveals that the connection has remained stable over time.

## 5 Analysis of factors affecting the tourism green development efficiency in the Beijing–Tianjin–Hebei urban agglomeration

### 5.1 Selection of influencing factors

To meet the requirements for comprehensive and coordinated development across the economy, politics, society, and ecology, as outlined in the "Plan for Coordinated Development of the BTH Urban Agglomeration," this paper investigates factors affecting the green development efficiency of the tourism industry in the region. Given the interdisciplinary nature of tourism research, and to ensure data availability and comparability, the paper selects six indicators from the economy, culture, politics, and market environment to comprehensively examine these factors. The following indicators are included:

(1) Economic development level (Eco), is considered an objective economic phenomenon that has a significant impact on regional tourism efficiency in terms of capital investment, technological development, and tourism resource transformation efficiency. The level of regional economic development directly affects inter-regional tourism project cooperation, which in turn affects the development level of tourism efficiency network structure (Liu and Wu, 2019). This study uses GDP per capita to characterize the level of regional economic development, which has been previously used in research practices (Liu *et al.*, 2016; Su *et al.*, 2018).

(2) Industrial structure (IS), is viewed as the intuitive reflection of the interaction and collaboration of factors in the tourism geographical space, with the combined force formed by different influencing factors after interconnection dominating the realization of this process and influencing the degree of development of tourism efficiency network structure through the change of intensity (Zhong *et al.*, 2016). The upgrading of industrial structure is an essential aspect of the transformation of economic growth and the improvement of the quality of economic growth and is also an inherent requirement for improving the efficiency of the tourism industry (Wang *et al.*, 2019; Zhang, 2023). As tourism is part of the tertiary industry, there is a strong correlation between the development of the tertiary industry and tourism. The better the economic development of the tertiary industry, the higher the economic efficiency of tourism. The economic efficiency growth of the tertiary industry has a significant impact on tourism efficiency. This study uses the value added of the tertiary sector as a share of GDP to measure the industrial structure, drawing on existing practices (Brida *et al.*, 2020).

(3) The degree of economic openness (Open). It is a crucial indicator that reflects a region's ability to proactively engage in expanding foreign economic trade. Improving the level of external openness plays a vital role in accelerating cross-border capital flows and

enhancing the efficiency of introducing and utilizing advanced technologies and management strategies (Lee and Brahmasrene, 2013). To characterize the degree of regional economic openness, this study draws on existing research results (Chen *et al.*, 2014) and uses the proportion of total imports and exports to GDP.

(4) The level of science and education (SE). Improving the level of science and education (SE) has been shown to contribute to the balanced development of regional economies, which is because higher-quality populations with improved education and scientific knowledge are more efficient in allocating production factors in tourism and promoting tourism development on a larger scale (Li *et al.*, 2023) thereby enhancing regional tourism eco-efficiency. In addition, the application of regional technological innovation and advancements in the tourism industry can improve the efficiency of energy resource utilization and enable tourism enterprises to save energy and reduce emissions (Medina *et al.*, 2022). To measure the level of science and education in a given region, this study follows the approach of previous research (Huang *et al.*, 2020) by using the proportion of local fiscal expenditures on science and technology and education relative to GDP.

(5) Tourism resource endowment (TRE). Tourism resource endowment is a key factor in measuring the attractiveness and development potential of regional tourism, with significant implications for both the scale of regional tourism and output efficiency. While the distribution of tourism resources is diverse, complex, and not easily quantified, tourists tend to prefer destinations with convenient transportation, rich tourism resources, well-developed infrastructure, and high-quality tourism products (Sun *et al.*, 2022a). As a result, only high-level world heritage sites and national A-class tourist attractions have the greatest appeal to tourists and can generate substantial tourism consumption, driving regional tourism economic growth. To reflect this, this study draws on previous research and focuses on thirteen A-class scenic spots in the BTH urban agglomeration as a way to characterize the region's tourism resource endowment.

(6) Government regulation (GR). Environmental resources have a public goods nature and the market often fails to address environmental issues in the process of economic development. Therefore, the government must use environmental policy tools to regulate and adjust the market (Day, 2022; Aguinis *et al.*, 2023). As the main responsible department for ecological environmental protection, the government should also take the lead in the development of ecotourism resources. Given the comprehensive nature of tourism and the many interests involved, government involvement in tourism development can provide a favorable political and legal environment for tourism development. Moreover, the green development of tourism and the optimization and upgrading of an industrial structure depends on the service capacity of government departments (Li *et al.*, 2024). To measure the government's involvement in environmental protection, this study uses the ratio of investment in environmental pollution control to investment in fixed assets.

## 5.2 Model identification and validation

### 5.2.1 Moran's I index

Building upon the insights gained from the study, it becomes evident that a significant spatial correlation characterizes the efficiency of tourism green development within the BTH urban agglomeration. To better comprehend its evolutionary trajectory, it is crucial to recognize and embrace its unique spatial attributes. Therefore, when delving into an examination of its cascading effects, the integration of a spatial panel model assumes critical importance. In this study, a geographic adjacency matrix is utilized to compute the Moran's I index (Table 5) for the designated region. The resulting data unequivocally affirm that the green development efficiency demonstrated by the BTH urban agglomeration maintains a robust spatial autocorrelation throughout the study's entire time frame. Furthermore, these distinct findings not only withstand rigorous testing at the 5% significance level but also provide compelling evidence endorsing the rationale behind the introduction of a spatial model.

**Table 5** Global Moran's I index for tourism green development efficiency in the Beijing–Tianjin–Hebei urban agglomeration (2001–2021)

| Year | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|---|---|---|
| Moran's I | 0.247 | 0.283 | 0.240 | 0.235 | 0.278 | 0.274 | 0.246 | 0.256 | 0.252 | 0.261 |
| Year | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| Moran's I | 0.239 | 0.234 | 0.244 | 0.241 | 0.238 | 0.254 | 0.246 | 0.247 | 0.268 | 0.259 |

### **5.2.2** Construction of spatial econometric model

The spatial lag model, spatial error model, and spatial Durbin model are commonly used spatial econometric models, differing in terms of spatial matrices and interaction terms among variables. Given that the spatial Durbin model comprehensively captures spatial correlations arising from variables and their interactions, and it reflects distinct spatial effects of various variables, this study employs the spatial Durbin model to estimate the influencing factors of green development efficiency in the tourism industry of the BTH urban agglomeration.

Then, we are taking into account the impact of dynamic effects and introducing time-lagged variables, denoted as $\tau TGDE_{i,\,t-1}$, as well as spatio-temporal lag terms, represented as $\mu TGDE_{i,\,t-1}$, to formulate a dynamic Spatial Durbin Model (SDM) for assessing the efficiency of tourism green development. To ensure the robustness of our findings, we employ three distinct forms of dynamic SDM estimation, each corresponding to different specifications of lag terms, as outlined below:

$$\begin{aligned} TGDE_{it} = {} & \tau TGDE_{i,t-1} + \rho WTGDE_{i,t-1} + \alpha_1 \ln Eco_{it} + \alpha_2 \ln IS_{it} + \alpha_3 \ln TR_{it} + \\ & \alpha_4 \ln Open_{it} + \alpha_5 \ln GR_{it} + \alpha_6 \ln SE_{it} + \beta_1 W \ln Eco_{it} + \beta_2 WI \ln S_{it} + \\ & \beta_3 W \ln TR_{it} + \beta_4 W \ln Open_{it} + \beta_5 W \ln GR_{it} + \beta_6 W \ln SE_{it} + \varepsilon_{it} \end{aligned} \tag{6}$$

$$\begin{aligned} TGDE_{it} = {} & \tau TGDE_{i,t-1} + \rho WTGDE_{it} + \lambda_1 \ln Eco_{it} + \lambda_2 \ln IS_{it} + \lambda_3 \ln TR_{it} + \lambda_4 \ln Open_{it} + \\ & \lambda_5 \ln GR_{it} + \lambda_6 \ln SE_{it} + \gamma_1 W \ln Eco_{it} + \gamma_2 W \ln IS_{it} + \gamma_3 W \ln TR_{it} + \gamma_4 W \ln Open_{it} + \\ & \gamma_5 W \ln GR_{it} + \gamma_6 W \ln SE_{it} + \delta_i + \mu_i + \varepsilon_{it} \end{aligned} \tag{7}$$

$$\begin{aligned} TGDE_{it} = {} & \mu TGDE_{i,t-1} + \rho WTGDE_{i,t-1} + \theta_1 \ln Eco_{it} + \theta_2 I \ln S_{it} + \theta_3 \ln TR_{it} + \theta_4 \ln Open_{it} + \\ & \theta_5 \ln GR_{it} + \theta_6 \ln SE_{it} + \psi_1 W \ln Eco_{it} + \psi_2 W \ln IS_{it} + \psi_3 W \ln TR_{it} + \psi_4 W \ln Open_{it} + \\ & \psi_5 W \ln GR_{it} + \psi_6 W \ln SE_{it} + \delta_i + \mu_i + \varepsilon_{it} \end{aligned} \tag{8}$$

where $\tau$, $\rho$, $\alpha$, $\beta$, $\lambda$, $\gamma$, $\theta$, and $\psi$ correspond to coefficients, $\delta_i$ signifies time-related effects, $\mu_i$ represents individual-specific effects, and $\varepsilon_{it}$ denotes random error components. The matrix $W$ represents spatial weights. To ensure the stability of the regression outcomes, the dependent variable is subjected to a logarithmic transformation.

**5.2.3** Spatial weight matrix

In the context of spatial correlation analysis, the initial step involves the construction of an appropriate spatial weight matrix, which effectively captures the extent of spatial interrelationships. In this endeavor, we undertook a comprehensive assessment of methodologies previously adopted by scholars (Li and Qi, 2018), meticulously balancing the merits and demerits of several options. These considerations encompassed the spatial adjacency matrix denoted as $W_1$, the geographical distance weight matrix represented by $W_2$, the economic distance weight matrix designated as $W_3$, the geographical-economic distance weight matrix expressed as $W_4$, and the nested weight matrix, denoted as $W_5$. Accounting for both the constraints inherent in the available data and the optimization of regression outcomes, our final selection for conducting spatial correlation analysis was the nested weight matrix. The nested weight matrix offers the distinctive advantage of simultaneously incorporating the influences of economic and geographical distances. It is defined as $W_5 = \varphi W_2 + (1-\varphi)W_3$, with the parameter $\varphi$ empirically set to 0.5, a choice substantiated by prior scholarship (Dong and Wang, 2019).

**5.2.4** Stationarity test

Before embarking on model construction, it is imperative to ascertain the independence of the variables. Numerous methods exist for detecting multicollinearity, with the variance inflation factor (VIF) being a commonly employed metric in regression analysis. The magnitude of the VIF value serves as an indicator of the severity of multicollinearity: the larger the VIF, the more pronounced the multicollinearity issue. It is widely accepted that a VIF exceeding 10 signifies a significant collinearity problem within the model. In our evaluation, we have utilized the VIF value to conduct a rigorous collinearity assessment. The findings presented in Table 6 reveal that the VIF values associated with the variables are all below the threshold of 10, thereby indicating that the variables exhibit a satisfactory degree of independence from each other (Table 6).

**Table 6** Collinearity test among variables

| | *Eco* | *IS* | *TR* | *Open* | *GR* | *SE* |
|---|---|---|---|---|---|---|
| *vif* | 2.231 | 3.156 | 4.114 | 2.143 | 1.248 | 1.087 |

Furthermore, the model's validity should be assessed based on the discriminatory approach suggested by Anselin (2004). When subjected to the likelihood-ratio test (LR test) and the Wald test, the data presented in Table 7 indicate that both tests pass the 5% significance threshold, providing a solid rationale for employing the SDM (Spatial Durbin Model).

**Table 7** Likelihood-ratio test and Wald test results for the spatial Durbin model

| | Value | *p* | | Value | *p* |
|---|---|---|---|---|---|
| Robust LM–lag | 36.792 | 0.000 | LR–SDM–SAR | 85.347 | 0.000 |
| Robust LM–error | 48.275 | 0.000 | Wald–spatial–lag | 26.924 | 0.030 |
| LR–SDM–SEM | 37.161 | 0.000 | Wald–spatial–error | 77.865 | 0.000 |

Note: Robust LM–Lag indicates a robust lagrange multiplier test for LM, where the null hypothesis suggests no spatial lag effects in the dependent variable. Robust LM–Error indicates a robustlLagrange multiplier test for LM, where the null hypothesis suggests no spatial lag effects in the error terms.

### 5.3 Results and analysis

#### 5.3.1 Spatial Durbin model estimation result and analysis

The results of the spatial Durbin model reveal that the tourism green development efficiency within the urban agglomeration showcases prominent positive spatial spillover effects, indicating a mutual influence among various influencing factors. Notably, the spatial Durbin model encompasses spatial lag terms for both the dependent variable and the explanatory variables, potentially introducing certain biases into the SDM estimation coefficients, as presented in Table 8.

The study found that the level of economic development, industrial structure, and science and education has a positive effect on the efficiency of tourism green development. Balsalobre-Lorente *et al*. (2021) found that there is a "U" shaped relationship between economic development and tourism green development efficiency. With the development of tourism in the BTH urban agglomeration, the supporting role of the tourism economy lays a good foundation for the improvement of the regional ecological environment, which in turn promotes the improvement of tourism green development efficiency. Regarding the industrial structure, economic growth is mainly reflected in the higher share of the tourism sector with a higher labor force and the replacement of traditional technology renewal. In recent years, the BTH urban agglomeration has achieved innovative breakthroughs in tourism products, driven by endogenous technological innovation, and their industrial added value has maintained long-term stable growth. Technological upgrading and added value growth have helped tourism save energy, reduce emissions and protect the ecological environment. Furthermore, the level of science and education can reflect the technological level of tourism to a certain extent. Technological progress promotes ecological production and improves the efficiency of energy and resource utilization in tourism. The higher the education level of the nationals, the higher their professional skill level, technological innovation ability, and environmental protection awareness, which is conducive to energy conservation.

The study revealed that tourism green development efficiency in the BTH urban agglomeration is negatively affected by factors such as the degree of openness, government regulation. This may be due to the fact that foreign investors in tourism prioritize economic gains, valuing the region's rich tourism resources, cheap labor, and huge tourism market. As a result, the government tends to relax environmental regulations to attract more foreign investment, leading to a series of ecological environmental problems. The BTH urban agglomeration is highly market-oriented, allowing for efficient resource allocation through competition, the price mechanism, and supply and demand. Too much macro regulation can hinder the formation of green economic systems such as the green capital market, green credit, and ecological compensation. Therefore, the government should regulate and control the market situation appropriately, playing a positive guiding role in the green development of tourism. Tourism resources are crucial to all tourism activities. The BTH urban agglomeration has numerous high-quality attractions, making it a significant tourist destination in China and the world. However, the scale of tourism economic development carries a greater environmental and social pressure, as the increase in tourists leads to an overloaded carrying capacity and triggers conflicts between urban indigenous and foreign tourists. These factors hinder the green development of the tourism industry.

**Table 8** Model estimation results

| Variable | BTH urban agglomeration | | | | Core hub and tourism regional center cities | | | | Tourism node cities | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Space and time fixed effects | Space and time fixed effects (bias correction) | Space and time random effects | Dynamic spatial Durbin panel | Space and time fixed effects | Space and time fixed effects (bias correction) | Space and time random effects | Dynamic spatial Durbin panel | Space and time fixed effects | Space and time fixed effects (bias correction) | Space and time random effects | Dynamic spatial Durbin panel |
| *WTGDE* | 0.295*** (2.625) | 0.196** (2.174) | 0.224** (2.425) | 0.287** (2.372) | 0.262** (2.336) | 0.239** (2.225) | 0.198** (2.237) | 0.279*** (2.856) | 0.236*** (2.774) | 0.219*** (2.669) | 0.258** (2.578) | 0.267*** (2.931) |
| ln*Eco* | 0.181*** (3.373) | 0.148*** (2.930) | 0.136 (0.441) | 0.192*** (3.262) | 0.036 (0.414) | 0.015 (0.091) | 0.018 (0.830) | 0.048 (0.609) | 0.127* (1.689) | 0.135* (1.787) | 0.133* (1.862) | 0.136* (1.899) |
| ln*IS* | 0.097*** (3.903) | 0.098** (2.910) | 0.116*** (3.109) | 0.106*** (3.688) | 0.126*** (3.256) | 0.115* (2.431) | 0.136* (2.167) | 0.132*** (3.891) | 0.134** (2.328) | 0.137** (2.476) | 0.177** (2.129) | 0.261*** (3.632) |
| lnO*pen* | –0.135*** (3.462) | –0.102*** (3.756) | –0.097*** (3.685) | –0.142*** (2.973) | –0.027*** (3.142) | –0.024* (1.941) | –0.031** (2.305) | –0.036*** (3.640) | –0.062* (1.627) | –0.071 (1.578) | –0.059 (1.449) | –0.115*** (2.728) |
| ln*SE* | 0.136** (2.262) | 0.109** (2.168) | 0.062** (2.408) | 0.149** (2.020) | 0.069** (2.501) | 0.062 (1.382) | 0.052 (1.594) | 0.077*** (2.617) | 0.066** (2.435) | 0.042** (2.128) | 0.082** (2.311) | 0.076*** (4.327) |
| ln*TRE* | 0.058* (1.868) | 0.043 (1.148) | 0.126* (1.765) | 0.066* (1.789) | 0.139* (1.854) | 0.107 (1.264) | 0.124 (1.537) | 0.128* (1.889) | 0.067* (1.945) | 0.072 (1.296) | 0.083 (1.448) | 0.052 (1.625) |
| ln*GR* | –0.048** (2.129) | –0.053** (2.233) | –0.021*** (5.354) | –0.059** (2.457) | –0.071*** (4.072) | –0.056*** (3.318) | –0.048** (2.439) | –0.065*** (3.976) | –0.067** (2.546) | –0.071** (2.264) | –0.078** (2.362) | –0.089** (2.478) |
| *W*ln*Eco* | 0.236*** (3.780) | 0.245*** (2.890) | 0.183*** (3.102) | 0.259*** (3.718) | 0.267*** (3.431) | 0.293*** (2.966) | 0.257*** (3.249) | 0.257*** (4.125) | 0.272*** (3.955) | 0.269*** (2.827) | 0.273*** (2.917) | 0.285*** (3.293) |
| *W*ln*IS* | 0.148*** (3.519) | 0.115*** (3.823) | 0.106** (2.145) | 0.194*** (3.676) | 0.126** (2.381) | 0.121 (1.908) | 0.118 (1.801) | 0.129*** (4.371) | 0.247** (2.450) | 0.265** (2.256) | 0.231** (2.123) | 0.282** (2.146) |
| *W*ln*Open* | –0.132** (2.126) | –0.129** (2.314) | –0.097 (1.390) | –0.147** (2.020) | –0.085 (1.560) | –0.138** (2.318) | –0.107 (1.641) | –0.076* (1.659) | –0.126 (1.228) | –0.134 (1.347) | –0.115 (1.415) | –0.118 (1.229) |

(*To be continued on the next page*)

**(*Continued*)**

| Variable | BTH urban agglomeration | | | | Core hub and tourism regional center cities | | | | Tourism node cities | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Space and time fixed effects | Space and time fixed effects (bias correction) | Space and time random effects | Dynamic spatial Durbin panel | Space and time fixed effects | Space and time fixed effects (bias correction) | Space and time random effects | Dynamic spatial Durbin panel | Space and time fixed effects | Space and time fixed effects (bias correction) | Space and time random effects | Dynamic spatial Durbin panel |
| *W*ln*SE* | 0.049** (2.372) | 0.052** (2.223) | 0.032*** (5.613) | 0.059** (2.496) | 0.047*** (4.028) | 0.056*** (3.185) | 0.045*** (2.992) | 0.035*** (4.613) | 0.071** (2.526) | 0.078** (2.347) | 0.065** (2.432) | 0.092** (2.356) |
| *W*ln*TRE* | 0.105** (2.036) | 0.103** (2.182) | 0.115** (2.361) | 0.146** (2.545) | 0.121** (2.013) | 0.107 (1.432) | 0.125 (1.392) | 0.135** (2.652) | 0.126** (2.272) | 0.136** (2.285) | 0.109** (2.233) | 0.134*** (2.987) |
| *W*ln*GR* | –0.143* (1.819) | –0.146** (2.237) | –0.134** (2.315) | –0.153* (1.846) | –0.249** (2.371) | –0.164* (2.204) | –0.138* (2.156) | –0.221*** (2.837) | –0.203* (1.962) | –0.211*** (2.695) | –0.235** (2.581) | –0.206** (2.322) |
| C | –3.041*** (4.914) | –3.142*** (4.916) | –3.097*** (4.870) | –3.941*** (4.851) | –2.197*** (5.873) | –2.876*** (5.224) | –2.417*** (6.551) | –2.548*** (4.867) | –2.159*** (4.879) | –2.375*** (4.531) | –2.969*** (4.438) | –3.214*** (5.267) |
| Adjust $R^2$ | 0.797 | 0.698 | 0.712 | 0.797 | 0.818 | 0.770 | 0.781 | 0.818 | 0.836 | 0.784 | 0.773 | 0.795 |
| Wald test (SAR) | 89.012 (0.000) | 105.245 (0.000) | 116.364 (0.000) | 89.012 (0.000) | 124.461 (0.000) | 115.523 (0.000) | 112.432 (0.000) | 124.464 (0.000) | 119.357 (0.000) | 112.561 (0.000) | 106.323 (0.000) | 96.591 (0.000) |
| Wald test (SEM) | 93.613 (0.000) | 106.671 (0.000) | 108.192 (0.000) | 93.615 (0.000) | 140.153 (0.000) | 132.273 (0.000) | 126.542 (0.000) | 140.151 (0.000) | 126.232 (0.000) | 125.106 (0.000) | 98.701 (0.000) | 106.718 (0.000) |
| Wald test (SP) | 105.492 (0.000) | 106.325 (0.000) | 126.417 (0.000) | 135.249 (0.000) | 137.532 (0.000) | 120.548 (0.000) | 116.413 (0.000) | 136.632 (0.000) | 98.719 (0.000) | 127.328 (0.000) | 119.659 (0.000) | 159.108 (0.000) |
| Observation No. | 273 | 273 | 273 | 273 | 105 | 105 | 105 | 105 | 168 | 168 | 168 | 168 |
| Cities No. | 13 | 13 | 13 | 13 | 5 | 5 | 5 | 5 | 8 | 8 | 8 | 8 |

Note: (1) The core hub and regional center cities are studied together, considering that the small sample size of core hub cities may easily cause the problem of small panel data capacity. (2) Wald test (SP) means Wald simultaneous parameter test. (3) The figures in parentheses are the standard error values of model estimation. (4) ***; **; and * indicate significant at confidence levels of 1%, 5% and 10%, respectively.

### 5.3.2 Analysis of spatial effects decomposition results

The spatial Durbin model includes both lagged spatial terms of the dependent variable and lagged spatial terms of the independent variables, which may lead to certain biases in the estimated coefficients. Therefore, this study employs the effect decomposition method to decompose the overall effect on the dependent variable into direct effects and indirect effects (Table 9).

**Table 9** Direct utility and indirect utility of tourism green development efficiency in the Beijing–Tianjin–Hebei urban agglomeration

| | BTH urban agglomeration | | | Core hub and tourism regional center cities | | | Tourism node cities | | |
|---|---|---|---|---|---|---|---|---|---|
| | Direct utility | Indirect utility | Total utility | Direct utility | Indirect utility | Total utility | Direct utility | Indirect utility | Total utility |
| ln*Eco* | 0.331*** | 0.137** | 0.468 | 0.287*** | 0.158* | 0.445 | 0.295** | 0.197** | 0.492 |
| ln*IS* | 0.492*** | 0.085 | 0.577 | 0.416** | 0.217 | 0.633 | 0.372*** | 0.211* | 0.583 |
| lnO*pen* | –0.165 | 0.050 | –0.115 | 0.158* | 0.130 | 0.288 | –0.186** | 0.106 | –0.080 |
| ln*SE* | 0.208*** | 0.103* | 0.311 | 0.194*** | 0.035 | 0.229 | –0.132 | 0.114 | –0.018 |
| ln*TRE* | –0.106** | 0.094** | –0.012 | –0.069 | 0.101 | 0.032 | 0.255* | 0.149 | 0.404 |
| ln*GR* | –0.074** | 0.016 | –0.058 | 0.103* | 0.084 | 0.187 | –0.108* | 0.050 | –0.058 |

Note: ***, **, * indicate $p \leqslant 0.01$, $0.01 < p \leqslant 0.05$, and $0.05 < p \leqslant 0.1$, respectively.

Based on the perspective of core hub cities and tourism regional center cities, several factors have a significant positive impact on tourism green development efficiency including economic development level, industrial structure, science and education level, openness, and government regulation. Among these factors, industrial structure has the greatest impact on tourism green development efficiency. In addition, the level of science and education is positively correlated with the green development efficiency of tourism in these cities. The high investment in education and relatively high level of economic development in these areas, as well as their strong economic foundation and high level of modernization, are some of the reasons for this correlation. Technological innovation is mostly concentrated in the tertiary industry, and the focus on innovation and application of green technology, and the improvement of regional ecological environment, also have a greater impact on the green development efficiency of tourism. Government regulation is another important factor that can effectively improve tourism green development efficiency. The improvement of tourism green development efficiency depends on government intervention in the tourism economy and tourism environment, and the intensity of such intervention can effectively promote the synergistic development of the tourism economy, society, and ecological environment within a reasonable range. According to the environmental economic theory, the relationship between “trade and environment” is an important consideration when discussing the opening up of the world. In general, trade can lead to growth. High levels of per capita income will encourage the public to increase their demand for environmental protection, which in turn will prompt the government to further tighten environmental regulations. This will encourage businesses to use environmentally friendly and energy-saving technologies, reduce pollution emissions, and promote the coordinated development of the environment and the economy. Core hub cities and central cities of tourist areas with good trade environments and developed import and export trade further enhance economic efficiency and output through free trade and investment, thereby improving the output level of resource and environmental inputs. Under the influence of economies of scale, environmental quality will gradually shift from deterioration to improvement, thus enhancing the regional tourism green development efficiency. However, it should be noted that the tourism resource endowment is negatively correlated with the green development efficiency of tourism in regional hub cities, which can be attributed to the concentration of high-quality and popular tourism resources in the BTH urban agglomeration, and which leads to a higher concentration of tourists and indirectly increases the burden on the tourism ecological environment. As a result, the relationship between tourism resource endowment and tourism green development efficiency is not significant. These factors should be carefully considered when promoting green development efficiency in tourism in core hub cities and tourism regional center cities.

Based on the analysis of tourism node cities, several factors have a significant impact on the efficiency of tourism green development. The economic development level, industrial structure, and tourism resource endowment have positive coefficients, indicating that these factors are positively correlated with tourism green development efficiency. With the promotion of the BTH synergistic development, the regional development and modernization level of tourism node cities are improving, and the economic level is playing a more prominent role in the development of tourism. The proportion of tertiary industry to GDP directly determines the degree of agglomeration of the tourism industry, the scale of agglomeration, the level of development, and the effect of energy saving and emission reduction. The optimization of industrial structure is closely linked to regional resource allocation and characteristic industries.

Tourism resources are the foundation of all tourism activities, and high-quality tourism resources are an important factor affecting the efficiency of tourism green development in tourism node cities. Such resources attract tourists to the destination, bring tourism economic benefits, increase tourism jobs, and satisfy tourists' happiness. Although high-quality tourism resources may bring environmental and social pressure to the local area, they can effectively promote the green development of tourism within the range of environmental tolerance. However, the level of science and education, the degree of openness to the outside world, and government regulation are negatively related to the efficiency of tourism green development. Tourism node cities face pressures to further improve urbanization, optimize industrial transformation and upgrade, and focus on innovation in industrial production technology, while paying insufficient attention to green technological innovation and the output of such innovation. Additionally, there is a relatively lower degree of regional environmental protection and governance, which limits the impact of science and education, openness, and government regulation on tourism green development.

Although it is generally believed that opening up to the outside world can bring more foreign capital, advanced management experience, and environmental optimization technology to tourism development, the "Pollution Refuge Hypothesis" suggests that the higher the degree of opening up to the outside world, the more likely heavy pollution and high energy consumption enterprises will move to areas with lower thresholds (Eskeland and Harrison, 2003). As a result, the impact of opening up to the outside world on the efficiency of tourism green development in tourism node cities is not clear.

# 6 Conclusions and discussion

## 6.1 Conclusions

This paper aimed to measure the green development efficiency of tourism in the BTH urban agglomeration, analyze its spatio-temporal evolution pattern, and investigate the internal mobility and stability of its green development efficiency using Markov chain. Additionally, this study analyzed the factors that influence the green development efficiency of tourism in the area. Based on the findings, the following conclusions can be drawn:

(1) From 2001 to 2021, the average value of the green development efficiency of tourism in the BTH urban agglomeration increased from 0.770 in 2001 to 1.127 in 2021, indicating a generally high level but with significant fluctuations. The corresponding regional coefficient of variation (CV) decreased from 0.615 to 0.121. The spatial distribution pattern showed a "core hub city-tourism region" distribution, with a decreasing distribution pattern of "core hub city-tourism regional center city-tourism node city." The average values of the three regions were 1.319, 1.133, and 0.689, respectively, with the tourism node city showing the highest value, followed by the tourism regional center city and core hub city.

(2) The kernel density curve of tourism green development efficiency in the BTH urban agglomeration shifted to the right from 2001 to 2021, with an increased wave height, widened width, and an obvious "single peak" development pattern. These findings indicate a gradual improvement in the level of tourism green development efficiency, weakening polarization, decreasing regional gaps, and increased coordination. Additionally, the temporal evolution of tourism green development efficiency in BTH urban agglomeration showed strong smoothness, with a potential for reaching higher levels, but leapfrog development may be challenging. Concerning the spatial structure evolution, the connection pattern of tourism green development efficiency is relatively stable, while the spatial connection intensity is high between neighboring cities due to the law of distance decay.

(3) In general, there were positive correlations between the level of economic development, industrial structure, and science and education level, and the green development efficiency of tourism in the BTH urban agglomeration, with coefficients of 0.171, 0.494, and 0.108, respectively. However, the roles of openness, government regulation, and tourism resources were not significant. Among these factors, the level of economic development and the level of science and education are closely related to the region's modernization and development, while the degree of optimization of the industrial structure is closely related to the region's resource endowment and the layout of special industries. The role of government regulation needs careful consideration in conjunction with the level of marketization, and there are obvious regional differences in tourism resources. From a sub-regional perspective, the main factors affecting the efficiency of tourism green development in core hub cities and tourism regional center cities are the level of economic development, industrial structure, level of science and education, degree of openness, and government regulation, with the industrial structure having the greatest impact. The main factors that affect the growth of tourism green development efficiency in the BTH tourism node cities are the level of economic development, industrial structure, and tourism resources.

## 6.2 Discussion

The enhancement of tourism green development efficiency signifies that the tourism industry is able to effectively improve its economic and social benefits on the premise of reducing resource consumption and environmental impacts, thus promoting the long-term sustainable development of the tourism industry. The theoretical ccontribution of this study is to construct a comprehensive and systematic empirical model and theoretical framework to deeply analyze the evolutionary path and spatio-temporal evolutionary drivers of tourism green development efficiency in the BTH urban agglomeration. It identifies and evaluates the key factors affecting the green development efficiency of tourism in the BTH urban agglomeration, and reveals the specific mechanisms of these factors through empirical analysis. In addition, practical strategies are proposed to solve the problems of ecological degradation and unbalanced regional development in the process of tourism development, with a view to providing theoretical support and practical guidance for the coordinated development of tourism economy, tourism ecology and tourism society in the BTH urban agglomeration.

The tourism green development efficiency of the BTH urban agglomeration is improving, but there are still challenges that need to be addressed. The rapid urbanization and industrialization activities in the region may hinder the green development of the tourism industry, and the significant differences within the urban agglomerations also pose challenges. The successful bid for the 2022 Winter Olympics and the development of transportation infrastructure have enriched tourism resources and promoted the green development of the industry, but targeted improvement measures are needed to address the specific challenges faced by each region.

The dynamic evolution of tourism green development efficiency shows that there is a "club convergence" phenomenon, and the factors influencing the green development efficiency differ among core hub cities, tourism regional center cities, and tourism node cities. Therefore, policymakers should consider the actual regional development when implementing improvement measures, and focus on improving factors such as economic level, industrial structure, and tourism resources to enhance the green development efficiency of the tourism industry in each region. Overall, this study provides valuable insights for policymakers and practitioners in promoting the green development of the tourism industry in the BTH urban agglomeration.

(1) The core hub city should leverage its economic, social, and technological innovation advantages to promote Chinese-style modernization and encourage innovative and creative research and development activities in industries, scientific research institutions, and other sectors. It should also promote tourism energy conservation, optimal allocation and recycling of resources, ecological and environmental restoration, and other technologies that contribute to environmental protection. Furthermore, it should attract environment-friendly enterprises, actively cultivate green and low-carbon new industries, and create a pioneer and demonstration area for tourism green development. By connecting the dots and leading the way, it can drive the green development of tourism in other cities. To achieve these goals, the city should focus on creating a green landscape and building a strong city with integrated culture and tourism. This includes promoting all-area and all-season tourism and accelerating the construction of the Grand Canal cultural tourism belt. It should also develop red, rural, and ecological tourism to diversify its tourism offerings.

(2) Tourism regional center cities should focus on developing and building green, low-carbon, and environmentally friendly tourism projects by increasing infrastructure in-

vestments, with attractions as support. This includes developing green industries such as ecotourism and forest recreation to build a community where hosts and guests can share their experiences. To increase the public's awareness of ecological civilization ideas, multiple self-media platforms such as public accounts and microblogs should be operated simultaneously to popularize relevant expertise and enhance social attention to nature reserves. Moreover, the government should play a role in guiding and supporting the tourism industry. This includes urging the government to introduce corresponding laws and regulations to restrict the behavior of tourism enterprises, promoting the construction of key tourism projects, supporting the innovation and transformation of key tourism enterprises, and empowering the tourism industry with technology and culture. Additionally, tourism enterprises, cultural venues, and tourist attractions should be encouraged to develop online tourism and create a platform for online promotion and publicity, wherever possible.

(3) Tourism node cities should leverage the BTH tourism integration platform to introduce new technologies and concepts of low-carbon tourism. This includes integrating the concept of intelligent tourism into various aspects of the tourism experience, such as food, accommodation, travel, purchase, and entertainment, to continuously drive technological progress. To further promote the development of the tourism industry, these cities should guide the capital, talents, and management elements towards vertical integration and reorganization of tourism enterprises. This will help cultivate large tourism enterprise groups and tourism industry clusters with strong capabilities. By scientifically and reasonably enhancing the scale of the tourism industry and optimizing its structure, these cities can improve the overall competitiveness of their tourism industry.

### 6.3 Research limitations

The objective of this article is to scrutinize the definition of green development in the tourism industry and construct an efficiency evaluation system for tourism green development in the BTH urban agglomeration, in light of the current context of high-quality coordinated development in the region. To achieve this, we utilize the SBM–Undesirable model to measure the efficiency of tourism green development in the BTH urban agglomeration. Additionally, we depict the spatio-temporal evolution characteristics of tourism green development efficiency, the long-term transfer trend of tourism green development efficiency, and its influencing factors. Our study enriches the topic of externalities in tourism economics through economic evidence, deepens the rational understanding of tourism green development efficiency in the BTH, and provides scientific reference value and decision-making support for theoretical and practical research on tourism green development.

Tourism green development is a complex and comprehensive system, with intricate spatio-temporal evolution and multiple influencing factors involving various factors such as economic society and ecological environment. Relevant research is still in the exploratory stage, and the academic community has yet to form a relatively complete research system. Therefore, constructing a sound efficiency evaluation system for tourism green development will be a key focus of future research. At the same time, most current research is based on macroscopic levels, such as national, provincial, and urban agglomeration levels. Due to regional heterogeneity, future research should strengthen differentiated studies on small-scale levels, such as county and town levels, to promote the modernization of regional ecological governance and the deep integration of regional culture and tourism development. Moreover, the mechanism of tourism green development is intricate and influenced by both internal and external factors. Therefore, future research should concentrate on the internal development level of the industry and conduct studies on the influencing mechanism of tourism green development.

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