Original Research

# **Study on Food-Energy-Water Nexus and Synergistic Control of Tourism in Beijing**

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# Abstract

The rapid growth of tourism economy in Beijing has intensified the consumption of resources and the pollution of the environment, and the coupled relationship among food, energy, and water requires rigorous research and discussion. This study developed an environmental extended input-output model by combining 42 sectoral input-output tables and tourism statistics in Beijing. It also carried out the food-energy-water (F-E-W) accounting and evaluation of the tourism industry. Then, through structural decomposition driving force analysis, it proposed a synergistic F-E-W reduction strategy for the tourism industry in Beijing. Results of the study show that the F-E-W related sectors consume a total of 605.6 million m<sup>3</sup> of water and 21.1 million tons coal equivalent (tce) of energy to sustain the operation of the tourism industry in Beijing; the food supply group generates the largest tourism water footprint, accounting for 72.1%. The tourism direct group generates the largest tourism energy footprint, accounting for 58.3%; and the food and water supply groups are the key contributors to the F-E-W correlation. From 2012 to 2017, Beijing's tourism water footprint (TWF) decreased by 46.3%, and tourism energy footprint (TEF) increased by 23.7%. Structural decomposition analysis shows that the reduction in Beijing's TWF is driven by the changes in production structure. Conversely, the increase in TEF is driven by scale effects. Through eco-innovation of tourism enterprises, government environmental regulation of tourism and guiding travelers to green consumption can promote synergistic F-E-W emission reduction.

Keywords: Beijing, tourism, food-energy-water, nexus, measures to reduce emissions

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# Introduction

Tourism contributes 10% of the world's GDP and makes a significant contribution to world economic development, population employment, and cultural exchange [1]. However, tourism, which has been described as a "smoke-free industry," has also been criticized for resource consumption, environmental pollution, and ecological damage [2]. Studies show that in 2010, the global tourism system consumed 570.6 billion tons coal equivalent (tce), 138 billion tons of water and 39.4 megatons (Mt) of food, resulting in 1.12 billion tons of CO<sub>2</sub> emissions; by 2050, tourism's consumption of water resources will increase by 92%, and demand for land will increase by 189% [3]. The massive consumption of resources and waste discard has put enormous pressure on ecosystems in terms of resource availability and environmental carrying capacity. In this context, food, energy and water are included in the UN's 17 Sustainable Development Goals for 2030, namely "Goal 2: End hunger, achieve food security, improve nutrition and promote sustainable agriculture", "Goal 6: Provide water and sanitation for all and manage them sustainably", "Goal 7: Ensure access to affordable, reliable and sustainable modern energy for all" (United Nations, UN, 2015). The UN Sustainable Development Goals mention that by 2050, when the world's population increases to 9.6 billion, the natural resources needed to sustain the current lifestyle are equivalent to the total resources of three Earths combined. Achieving sustainable tourism development can improve the link between economic growth and environmental degradation in tourism, increase resource efficiency, and promote sustainable lifestyles.

Beijing is the capital of China, the sixth largest city in the world and a typical mega-city, with total tourism revenues of 89.32 billion US dollars in 2019, accounting for 17.6% of Beijing's GDP, 318 million domestic tourists, and 3.21 million foreign tourists in China [4]. The 321 million tourist arrivals have promoted Beijing's economic development but have also sharply increased the pressure on resources and the environment, increasing risk for long-term stable development of tourism. The sustainable development of Beijing's tourism industry urgently requires in-depth study. In the context of China's proposal to peak carbon by 2030 and carbon neutral by 2060, the greening and ecological development of Beijing's tourism industry is an inevitable choice for the sustainable development of a mega-city. An important approach to measure the sustainability of tourism is the nexus of food, energy and water (F-E-W nexus), which can optimize the allocation of tourism factors and improve resource efficiency and can provide a reference for the practice of sustainable tourism.

The concept of the "F-E-W nexus" was first introduced at the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil, in 1992 [5]. In January 2011, the Global Risks Report (6<sup>th</sup> edition), published by the World Economic Forum, identified the "Water-Energy-Food Nexus" risk cluster as one of the three most important risk clusters. In November of 2011, an international conference on the safety of the WEF-Nexus was held in Bonn to explore the pathways to a green economy. The conference pointed out that global climate change and social change have an impact on the production and consumption of food, energy, and water, and that the complex correlation among the three resources, tradeoffs, and potential contradictions are prevalent in the process of production, consumption, and management; the strategy based on any single resource will produce unexpected and serious consequences [6]. F-E-W sectors are interrelated, and the development of one department usually consumes the resources of the other two sectors [7]. Leveraging new data sources from the system is critical to advancing research and developing sustainability in F-E-W relationships [8].

The research on F-E-W is mostly carried out from the perspective of resource scarcity and interdepartmental correlation. In terms of resource scarcity, Lawford et al. [9] studied the competitive relationship between food production and bioenergy production under the conditions of a substantial increase in future demand for three resources and uncertain supply. D'Odorico et al. [8] collected the data of water footprint required for the production of specific types of energy and food to investigate the competitive relationship between energy and food for water demand in the global FEW. Venla et al. [10] assessed water demand in China's food and energy sectors for power generation, including coal, natural gas, biofuels, and nuclear power. From the perspective of interdepartmental correlation, Feng et al. [11] developed a physical input-output model to characterize the overall urban FEW relationship in the Detroit metropolitan area. White et al. [12] emphasized that "correlation" includes not only the resource and environmental footprints between FEW; considering the interdependence between FEW and regional ecosystems is also necessary. Owen et al. [13], based on the perspective of consumption, measured the changes in the FEW resource and environmental footprint driven by socio-economic needs and its close relationship with the economy and policies.

Researchers have used different methods to investigate the F-E-W nexus. Yang et al. [14] used a betweenness-based method and principal component analysis to study the Shanghai F-E-W Pressure Transmission Center department. Li et al. [15] used a multi-objective nonlinear programming model to inquire the only agricultural F-E-W relationship in the Heihe River Basin in China. AI-Ansari et al. [16] used the LCA method to study the F-E-W coupling in Qatar and conducted an environmental impact assessment on a variety of technology deployment scenarios under the premise of food self-sufficiency. Lee et al. [17] researched the nexus of FEW in China's tourism industry. Halbe et al. [18] discussed the possibility of achieving sustainable development of Cyprus from the perspective of different stakeholders by constructing an F-E-W feedback loop. In addition, Endo et al. [19] reviewed 37 related projects and discovered the importance of developing a unified framework that can be shared not only among scientists but also among social stakeholders to understand the WEF system's complexity. Research on the F-E-W relationship of the tourism industry under a unified framework can reveal its mechanism from a complex system, provide effective policy advice for the sustainable development of the tourism industry, and provide a reference for the F-E-W analysis of other sub-industries.

The widely used method to evaluate the efficiency of F-E-W systems is the footprint method [20]. The water footprint (WF) indicator is a measurement of water consumption composed of blue, green, and gray water [21-23]. WF can represent the direct water consumption in the production process of a product or service or the indirect water consumption in the product or service supply chain. The water footprint of a product or service refers to the amount of water needed to cover the entire supply chain to complete a product or service [24]. The tourism water footprint (TWF) is helpful for revealing and evaluating the real water possession and consumption of the tourism industry and then promoting the sustainable development of tourism [25]. Similar methods can be applied to energy consumption, such as energy footprint (EF). For the tourism industry, footprint indicators are typically used to describe the impact of tourism activities on resources and the environment. Direct Tourist Water Footprint or Energy Footprint refers to the water or energy consumption directly generated by tourists for their necessary tourism activities, such as transportation, accommodation, catering, drinking water, and entertainment [26, 27]. Indirect TWF or TEF refers to the sectors of the tourism supply chain, such as water or energy used by agriculture, electricity, and fuel [27, 28]. The unit of water and energy footprints are different: the unit of water footprint is m<sup>3</sup>, and the unit of energy footprint is ton coal equivalent (tce). A potential challenge is that food is a product and not a natural resource such as water and energy. By contrast, the food footprint research related to tourism needs further improvement. A large number of studies have found that the water footprint of tourism is closely to related agricultural sectors [23, 29]. The assessment of tourism water footprint (TWF) and tourism energy footprint (TEF) adopts top-down and bottom-up methods [30]. The top-down approach uses input-output analysis methods to assess the total input-output of a country or between countries. The input-output analysis method is an economic quantitative analysis method first proposed by the famous American economist Leontief in 1931. It is widely used to study the interdependence of inputs and outputs among various sectors in the economic system. The input-output model can reveal the indirect and easily neglected economic and technological links between various sectors of the national economy. The IO table is usually public, and a top-down method can be used to evaluate TEF [28, 31-35] and TWF [27, 29]. The IO method has high data requirements and cannot be directly applied at the micro-scale. The bottom-up approach generally uses the principle of full life cycle assessment (LCA) to study the TWF or TEF of tourism products or services [36, 37]. The LCA method is used to quantify the environmental impact of a given product or process throughout its life cycle [38]. Through a four-step process of target scoping, inventory analysis, impact assessment, and improvement analysis, the inputs, outputs, and potential environmental impacts of the subject of study throughout its life cycle are recorded, and elements that may have a significant impact on the environment are identified [39]. However, the LCA method often has difficulty including a complete required information, and the division of research boundaries and data collection are subjective [40,41]. The tourism industry involves a large number of sectors and products, and complex relationships exist among different sectors.

In summary, the coupling of food-energy-water is an important indicator of the sustainable development of the tourism industry [42], and it has received extensive attention from scholars. As the units of different resources are not identical, existing studies use multiple methods to assess single resources (e.g., water use in the energy and food production sectors) to quantify F-E-W relationships for specific production sectors [18, 42]. At the city and metropolitan scales, studies that use multiple resources to quantify tourism sectoral linkages are yet to be optimized. The current study includes two highly interconnected resource (water and energy) use streams in the F-E-W correlation analysis from the perspective of tourism resource supply in Beijing to establish a holistic analysis of the impact of each sector on resource consumption. The marginal contributions of the study are as follows: (1) Building an environmentally extended input-output model for the tourism industry, dividing the IO table of mega-city into a total of five groups of data according to tourism characteristics, namely, water supply, energy supply, food supply, tourism direct, and other groupscorresponding to the model for the accounting and evaluation of FEW in the tourism industry; (2) The overall distribution characteristics, relative change characteristics, and inter-subsystem flow characteristics of tourism FEW are analyzed from the perspective of food, energy, and water systematization, which can systematically reveal the relationship between "local and overall, static and dynamic" within the tourism FEW system compared with a single perspective, and analyzed the motivation behind the changes of various indicators; (3) The internal linkages of the tourism FEW system in mega-cities are revealed, the driving factors which affect the change in FEW are analyzed, and the sustainable development of the tourism industry in mega-cities is proposed.

The rest of the research is arranged as follows. Section 2 describes the material and methods. Section 3 details the results and discussion. Section 4 presents the research conclusion.

#### **Material and Methods**

# Environmentally Extended Input-Output Model (EEIO) Based on Water/Energy

#### Leontief Matrix Construction

To assess the water and energy footprints of urban tourism, regional IO tables, the data of tourism expenditure, and water and energy consumption were organized to construct an environmentally extended input-output model. The constructed matrix balance equation and Leontief inverse matrix are as follows:

$$X = AX + Y \tag{1}$$

$$X = (I - A)^{-1}Y$$
 (2)

In Equation (1-2), X is the column vector of total output, Y is the column vector of final demand, A is an n \* n consumption coefficient matrix, and I is an n \* n identity matrix. (I-A)<sup>-1</sup> is the Leontief inverse matrix of n \* n. n is the number of departments in the input-output (IO) table. The direct water intensity and direct energy intensity of department i are calculated as follows:

$$DW_i = \frac{W_i}{X_i} \tag{3}$$

$$DE_i = \frac{E_i}{X_i} \tag{4}$$

where  $DW_i$  is the direct water intensity of department i; and  $DE_i$  is the direct energy intensity of department i. Wi is the water consumption of sector i (unit is m<sup>3</sup>),  $E_i$  is the energy consumption of sector i (unit is ton of standard coal, tce for short), and  $X_i$  is the total output of sector i in the input-output table (unit is million dollars).

The 2012 and 2017 IO tables for Beijing were obtained from the Beijing Municipal Bureau of Statistics, and the IO tables for both years have 42 sectors, but the sectoral divisions are not entirely consistent. To better compare and analyze the characteristics and changes of TWF and TEF during the time period 2012-2017, the sectors of the original IO tables for 2012 and 2017 were split and combined and unified into 41 sectors. These 41 sectors were divided into five groups (shown in Table 1), Water supply Group (1 sector), Energy supply Group (5 sectors), Food supply Group (2 sectors), Tourism direct group (6 sectors), and Other group (27 sectors), to reveal the F-E-W relationship of tourism in Beijing. See Table 1 for an illustration.

The calculation formulas of tourism water footprint (TWF) and tourism energy footprint (TEF) are as follows:

Table 1. Full names, abbreviations, and groupings for each sector in the IO table.

Group	Full name(IO table)         Abbreviations			
Food supply	Agriculture, forestry, animal husbandry and fishery	Food products		
	Food and tobacco processing	Food processing		
Energy supply	Mining and washing of coal	Coal processing		
	Extraction of petroleum and natural gas	Petroleum		
	Processing of petroleum, coking, processing of nuclear fuel	Refined energy		
	Production and distribution of electric power and heat power	Electricity		
	Production and distribution of gas	Gas		
Water supply	Production and distribution of water	Water		
Tourism direct	Wholesale and retail trades	Wholesale		
	Transport, storage, and postal services	Transport		
	Accommodation and catering	Accommodation		
	Information transfer, software and information technology services	Information		
	Resident, repair and other services	Service		
	Culture, sports, and entertainment	Leisure		

Data source: Beijing 2012, 2017 input-output tables

$$TWF = DW(I - A)^{-1}Y_T$$
<sup>(5)</sup>

$$TEF = DE(I - A)^{-1}Y_T$$
(6)

where DW and DE are both 41\*1 column vectors of water and energy use intensity.  $Y_T$  is a 41\*1 tourism expenditure vector (unit is million dollars). Using the various expenditures in the tourism statistics data as the data of the direct tourism sector, the other sectors are 0, which constitutes a  $Y_T$  vector of 41\*1. In the study, Beijing's tourism consumption

In the study, Beijing's tourism consumption expenditure data in 2012 and 2017 and other related data come from the Beijing Statistical Yearbook (2012; 2017) and Beijing Tourism Statistics Handbook (2012; 2017).

#### Structural Decomposition Analysis (SDA)

To dissect the drivers of changes in the F-E-W footprint of the tourism industry, a decomposition analysis model of the water and energy footprints of the tourism industry is developed, and factor decomposition analysis is carried out. The structural decomposition analysis (SDA), based on input-output techniques, combines input-output techniques with factor decomposition analysis to analyze changes in the total output, structural changes, development rates, and growth in energy consumption in an economic system, revealing the driving forces of each sector in the IO table.

#### Structural Decomposition Analysis Model of the Water Footprint of the Tourism Industry

$$\Delta TWF = TWF_{(x)} - TWF_{(x-1)}$$
  
=  $DW_x P_x C_x T_x - DW_{(x-1)} P_{(x-1)} C_{(x-1)} T_{(x-1)}$   
=  $(\Delta DW) P_x C_x T_x + DW_{(x-1)} (\Delta P) C_x T_x \cdot$   
+  $DW_{(x-1)} P_{(x-1)} (\Delta C) T_x + DW_{(x-1)} P_{(x-1)} C_{(x-1)} (\Delta T)$   
(7)

where X and (X-1) represent 2017 and 2012, respectively.  $\Delta$  represents the increase or decrease in related variables from 2012 to 2017, such as  $\Delta DW = DW_{2017} - DW_{2012}$ . The four variables in the model represent the independent effects of the intensity of direct water consumption (DW), the production structure of the economic system (P), the composition of tourism expenditure (C), and total tourism expenditure (T) when the other three variables are constant.

Structural Decomposition Analysis Model of the Energy Footprint of the Tourism Industry

$$TEF = TEF_{(x)} - TEF_{(x-1)}$$

$$= DE_{x}P_{x}C_{x}T_{x} - DE_{(x-1)}P_{(x-1)}C_{(x-1)}T_{(x-1)}$$
  
$$= (\Delta DE)P_{x}C_{x}T_{x} + DE_{(x-1)}(\Delta P)C_{x}T_{x}$$
  
$$+ DE_{(x-1)}P_{(x-1)}(\Delta C)T_{x} + DE_{(x-1)}P_{(x-1)}C_{(x-1)}(\Delta T)$$
  
(8)

The four variables in the model represent the independent effects of the intensity of direct energy consumption (DE), the production structure of the economic system (P), the composition of tourism expenditure (C), and total tourism expenditure (T) when the other three variables are constant.

#### **Results and Discussion**

# Descriptive Statistical Analysis of the Water and Energy Footprints of the Tourism Industry in Beijing

To reveal the impact of each sector on the composition of the tourism footprint in Beijing, a descriptive statistical analysis was carried out on the results of the tourism footprint accounting.

# Descriptive Statistical Analysis of the Water Footprint of the Tourism Industry in Beijing

On the bases of the water consumption data and input-output analysis in Beijing, the water footprint of tourism industry in Beijing and its composition were accounted for as shown in Fig. 1a). In 2017, the water footprint of tourism industry in Beijing was 605.6 million m<sup>3</sup>, among which, the food supply group had the highest water footprint with 436.4 million m<sup>3</sup>, accounting for 72.1%. The other group came second with 90.9 million m<sup>3</sup>, accounting for 15%, The energy supply group ranked third with 63.2 million m<sup>3</sup>, accounting for 10.4%. Finally, the water supply group ranked last with 0.6 million m<sup>3</sup>, accounting for 0.09%, less than 0.1%.

The highest proportion of the water footprint of the tourism industry in the food supply group is due to the fact that tourists are full of freshness and curiosity about exotic diets, that is, "food pursuit of novelty" (Neophylic) [43], which piques their curiosity on the characteristics of travel destinations; additionally, the greater physical exertion during the travel activities also increases the demand for food. For businesses, the use of promotional tools to stimulate food consumption is an important means to increase tourism revenue. Local governments create city business cards through policy support and special food promotion and stimulate travelers to purchase local food and its derivatives with the help of cultural elements to promote regional economic development. Food also requires a large amount of water resources in the production process,



Fig. 1. Composition of the footprint of the tourism industry in Beijing in 2017: a) Tourism water footprint, b) Tourism energy footprint.

and the indirect water footprint of food products is a major component of the tourism water footprint.

Among the others group, the textile sector has the largest water footprint at 32.7 million m<sup>3</sup>, accounting for 5.4% of the tourism water footprint. This finding is due to the large indirect water footprint generated by the frequent washing of textiles such as bath towels, bed sheets, and disposable slippers used in the accommodation.

In the energy supply group, the electricity sector has the largest water footprint at 32.3 million  $m^3$ , accounting for 5.3% of the tourism water footprint. The electricity, heat, and other energy sources used in the tourism industry require a large amount of water for equipment cooling and energy acquisition and transportation during the production process.

Among the tourism direct group, the accommodation sector has the largest water footprint at 14.5 million m<sup>3</sup>, accounting for 1.7% of the tourism water footprint. The processing and preparation of food and beverages in the catering sector, the use of large diameter taps and showerheads in the accommodation sector, and the high frequency of cleaning all increase water consumption.

# Descriptive Statistical Analysis of the Energy Footprint of the Tourism Industry in Beijing

Based on Beijing's energy consumption data and input-output analysis, the energy footprint of Beijing's tourism industry and its composition have been calculated as shown in Fig. 1b). Fig. 1b) shows the component distribution of the energy footprint of Beijing's tourism industry in 2017. In 2017, the energy footprint of Beijing's tourism industry was 21.1 million tce. Among them, the tourism direct group has the largest energy footprint, 12.3 million tce, accounting for 58.3%. The energy supply group is next, with 4.14 million tce, accounting for 19.6%. The other groups are third, with 3.5 million tce, accounting for 16.4%. The food supply group is the fourth, 1.1 million tce, accounting for 5.1%. The last is the water supply group, 0.12 tce, less than 1%.

In the tourism direct group, the transport sector have the largest energy footprint, with 6.1 million tce, accounting for 28.9%; the accommodation sector are the next with 5.0 million tce, accounting for 23.6%. Tourists will consume energy when traveling to and from their travel destinations and when traveling in scenic spots. In order to satisfy a comfortable travel experience, the demand for electrical appliances such as air conditioners and TVs will increase power consumption; merchants will attract tourists to use electronics throughout the day. Advertising on the display shows that the restaurant needs to consume natural gas, electricity and other energy to cook food

In the energy supply group, the refined energy sector has the largest energy footprint at 3.1 million tce, accounting for 14.7% of the energy footprint of the tourism industry, which is consistent with the energy demand for transportation in tourism activities where fuel is the mainstay.

Among the others group, the real estate sector has the largest energy footprint at 0.8 million tce, accounting for 3.6% of the tourism energy footprint, followed by the leasing services sector, 0.6 million tce, about 3.0%. Emerging immersive tourism patterns have increased demand for short-term rentals of housing in tourist locations, driving increased energy consumption.

# Analysis of Direct and Indirect Footprint Correlations in the Tourism Direct Sector

To further analyze the linkages between the six direct tourism sectors and other sectors, the tourism



Fig. 2. Correlation analysis of water footprint of direct tourism sector in Beijing in 2017.

footprint was divided into two categories: direct and indirect footprints. Then, the main paths of tourism footprint generation were identified.

# Analysis on the Correlation of Water Footprint of the Direct Sector of Tourism

Fig. 2 shows the composition of the direct and indirect water footprints of the tourism direct sectors in Beijing in 2017. As shown in Fig. 2, the left axis shows the six tourism direct sectors, namely, the accommodation, service, leisure, wholesale, information, and transport sectors. The tourism direct sector generates a direct footprint and an indirect footprint, while the non-tourism direct sector generates only an indirect footprint. The material flows from left to right represent the water footprint flows of the six sectors. The right axis comprises the direct and indirect water footprints, with the latter including the food, water, and energy supply groups and the other group.

The indirect water footprint accounts for 98.0% of the water footprint. It is 47.9 times of the direct water footprint, among which the food supply group has the largest water footprint of 436.4 million m<sup>3</sup>, accounting for 72.1% of the water footprint. The largest water footprint is the indirect water footprint between the accommodation sector and the food supply group, which is 390.0 million m<sup>3</sup>, accounting for 64.4% of the water footprint, followed by the indirect water footprint from the accommodation sector to the other group at 42.5 million m<sup>3</sup>, accounting for 7.0% of the water footprint. The food supply sector has the largest indirect water footprint, indicating that the consumption of water is not in the food itself but in the indirect consumption of its supply chain.

# Analysis on the Correlation of Energy Footprint of the Direct Sector of Tourism

Fig. 3 shows the composition of the direct and indirect energy footprints of the tourism direct sectors in Beijing. As shown in Fig. 3, the left axis shows the six tourism direct sectors, namely, the accommodation, service, leisure, wholesale, information, and transport sectors. The material flows from left to right represent the energy footprint flows of the six sectors. The right axis shows the direct energy footprint of tourism and the indirect energy footprint, which is distributed in the food, water, and energy supply groups and the other groups. The indirect energy footprint is 12.5 million tce, which is 1.5 times higher than the direct energy footprint. The largest indirect energy footprint is in the other group, which is 7.2 million tce, accounting for 57.5% of the indirect energy footprint. The largest energy footprint is the direct energy footprint of the accommodation sector, 4.7 million tce, accounting for 22% of the energy footprint, followed by the direct water footprint of the transport sector, 3.0 million tce, accounting for 14.1% of the energy footprint.

#### Analysis of F-E-W Nexus in the Tourism Industry

### Analysis of the Relative Footprint of Tourism F-E-W

To systematically analyze the impact of each sector in the F-E-W supply group on the footprint of the tourism industry, we combine the water footprint of the tourism industry with the energy footprint of the tourism industry and conduct a relative footprint analysis of each department in the F-E-W system.

We further analyze the footprint distribution in the F-E-W supply group; evaluate the relative value of



Fig. 3. Correlation analysis of energy footprint of direct tourism sector in Beijing in 2017.

TWF and TEF of each department in the food, energy, and water supply groups; and divide the relative water footprint and energy footprint of the department into four quadrants as shown in Fig. 4. Fig. 4 presents an analysis of the relative water footprint and energy footprint of the food-energy-water supply groups in Beijing in 2017. In the food supply group, the food product sector appears in Quadrant I, which means that the agriculture sector requires a lot of water and energy. In the energy supply group, refined energy sector appears in Quadrant II, which shows that it consumes more energy than the other energy supply sectors and consumes relatively less water resources. Gas sector is in the quadrant III; it is the sector in the energy supply group that consumes relatively little water and energy. The electricity and petroleum sectors are in quadrant IV; they have a small demand for energy and a

relatively more demand for water resources. The water sector consumes less energy and water resources. Most sectors are distributed along the TWF axis or TEF axis, indicating that most sectors unilaterally consume more energy and water resources. Only the agriculture, forestry, animal husbandry, and fishery products consume large amounts of water and energy.

# Analysis of F-E-W Footprint Flow of Tourism Industry

To reveal the mechanism of footprint generation within the three F-E-W supply groups, a tourism F-E-W footprint flow analysis was conducted. Fig. 5 shows the water footprint and energy footprint flows among the food, energy, and water supply groups. Fig. 5 shows the food-energy-water correlations in Beijing in 2017.



Fig. 4. Analysis of the relative footprint of the food-energy-water supply groups in Beijing in 2017.



Fig. 5. Food-energy-water correlations in Beijing, 2017.

The water supply group provided 62.2 million m<sup>3</sup> of TWF to the energy supply group, 436.4 million m<sup>3</sup> of TWF to the food supply group, and 0.6 million m<sup>3</sup> of TWF to the water supply group itself. The energy supply group provided 0.1 million tce of TEF to the water supply group, 1.1 million tce of TEF to the food supply group, and 4.1 million tce of TEF to the energy supply group itself. The F-W-E supply group consumes a total of 500.2 million m<sup>3</sup> of TWF and 5.4 million tce of TEF to the tourism industry in Beijing.

# Analysis of the Relative Changes in the Footprint of Each Department of the F-E-W Supply Group in Beijing from 2012 to 2017

To further analyze the changing characteristics of the tourism footprint in Beijing, a dynamic analysis based on time series is conducted. During the five-year

period from 2012 to 2017, the water footprint of tourism in Beijing has decreased by 521.4 million m<sup>3</sup>, and the energy footprint has increased by 4.1 million tce. Fig. 6 shows the relative changes in the footprints of the food, energy, and water supply groups. Fig. 6 is an analysis of the relative changes in the footprint of each department of the F-E-W supply group in Beijing from 2012 to 2017. For the tourism water footprint, the figure shows that only the refined energy sector in the energy supply group shows a significant increase in the tourism water footprint of 29%. The food processing sector in the food supply group and the water sector in the water supply group show no significant changes, and the TWFs of the remaining sectors show different degrees of reduction. The petroleum sector (extraction) in the energy supply group has the largest proportional reduction in TWF at 87%.

Regarding the energy footprint of the tourism industry, the energy consumption of the gas sector in the



Fig. 6. Relative change of Beijing's footprint from 2012 to 2017.

five years from 2012 to 2017 has increased significantly, reaching 791%; followed by the water sector at 197%, and the two sectors of the food supply group showed a slight decline. The petroleum sector of the energy supply group has achieved the largest reduction in the energy footprint of the tourism industry, reaching 99.5%. Comparing the water and energy footprints, reducing the water footprint is easier than reducing the energy footprint. Moreover, the petroleum sector has achieved the largest reduction in the vater and energy footprints of the tourism industry at the same time.

#### Analysis of Driving Forces Influencing Factors

To reveal the internal driving forces of changes in Beijing's tourism industry footprint, the structural decomposition analysis method (SDA) is used to analyze the impact of the four driving forces. Fig. 7 shows the decomposition result from a decomposition analysis of Beijing's tourism industry footprint changes in 2012-2017.

As shown in Fig. 7a), in the five years from 2012 to 2017, the water footprint of Beijing's tourism industry has been reduced by 46.3%, and the production structure of the economic system (P) plays the most important role, reducing Beijing's TWF by 61.7%. The second is the intensity effect of water (DW), which promotes the reduction of TWF by 38.8%. The composition of tourism expenditure has no significant impact on the TWF of Beijing's tourism industry, but the total tourism expenditure increases TWF by 54.3%. The energy footprint of Beijing's tourism industry has increased by 23.7%. Among the four driving factors, total tourism expenditure has a positive impact on TEF, which increases TEF by 54.3%, and direct energy consumption intensity (DE) reduces TEF by 24.7% as shown in Fig. 7b). In the decomposition of TWF and TEF, the impact of changes in the composition of tourism expenditure is less than 1.5%, which shows that the composition of tourist expenditure in Beijing's tourism activities has a limited driving force on the overall water or energy footprint. SDA results show that total tourism



Fig.7. Decomposition analysis of footprint changes in Beijing's tourism industry from 2012 to 2017: a) water footprint decomposition analysis, b) energy footprint decomposition analysis.

Table 2. Decomposition of the driving forces of the F-E-W water footprint.

Driving force Group	Direct water consumption		Production structure		Composition of tourism expenditure		Total tourism expenditure	
Food supply		-16.10%		-54.38%		-0.47%		38.28%
Energy supply		-22.26%		-6.68%		-0.63%		12.38%
Water supply		-0.09%		-0.06%		0.00%		0.03%

Table 3. Decomposition of the driving forces of the F-E-W energy footprint.

Driving force Group	Direct consur	Direct energy consumption Pro		Production structure		Composition of tourism expenditure		Total tourism expenditure	
Food supply		-1.53%		-5.19%		0.04%		4.58%	
Energy supply		2.89%		-7.15%		-0.56%		10.24%	
Water supply		0.03%		0.31%		0.00%		0.13%	

expenditure is the main factor leading to the growth of TWF and TEF in Beijing, and production structure is the main driving force for the reduction of TWF. The intensity of direct water and energy consumption slows down water and energy consumption. The direct utilization coefficient reflects the level of technological innovation. The improvement and innovation of waterand energy-saving technologies can effectively reduce TWF and TEF. The improvement of the economic system's production structure has a significant effect in reducing TWF.

Further exploring the impact of drivers on the W-E-F supply group, Tables 2 and 3 show the SDA results of TWF and TEF changes in the W-E-F supply group, respectively. Over the five-year period 2012–2017, the production structure of Beijing food supply group has a significant slowing effect on the increase in TWF and TEF, contributing to a decrease in TWF by 54.38% and TEF by 5.19%, both of which exceed the effect of the direct intensity factor. Total tourism spending in the food and energy supply groups is the main factor in the increase of TWF and TEF, which is due to the increase in income level that promotes the growth of water and energy footprints by boosting tourist spending on food and transportation.

#### Conclusions

This study analyzes the correlation among food, energy, and water in the tourism industry in Beijing, and it reveals the driving factors for changes in energy and water consumption. The results show that among tourism-related activities in Beijing, the food product sector consumes the most water, and the direct tourism sector consumes the most energy. The key F-E-W relationship exists between the food and water supply groups. From 2012 to 2017, the production structure of the economic system was the main driving factor for the decrease in TWF, and total tourism expenditure was the main driving factor for the increase in TEF.

The food supply group generates more than 70% of Beijing's tourism TWF. Among them, the TWF generated by the food product sector is 2.4 times of the other 41 sectors combined. Various agricultural, forestry, animal husbandry, and fishery products consume the most water resources in the manufacturing process. The indirect water and indirect energy footprints of the six direct tourism sectors were significantly higher than the direct footprint. The indirect water footprint between the accommodation sector and the food supply group is more than the sum of the other five direct tourism sectors, which is 390.0 million m<sup>3</sup>, accounting for 64.4%. The direct tourism group consumes the most energy to maintain the normal operation of the tourism industry, including transportation, accommodation, and catering, to name a few. It also generates more TEF than the sum of the other groups. The largest energy footprint consumption was the direct use of the accommodation sector, which was 4.65 million tce, accounting for 22.0%. The distribution of energy footprint of direct tourism sectors is relatively balanced.

The food and water linkages are the key to the F-E-W correlations of Beijing's tourism industry. The water supply group provides water to the food supply group and consumes less of its own water, while the energy supply group provides most of the energy it consumes. The results of the association analysis reveal the importance of the accommodation and transport sectors in reducing the water and energy footprints of tourism.

During the 5 years from 2012 to 2017, the adjustment of Beijing's production structure of the economic system played a key role in reducing the region's tourism water footprint. The total tourism spending showed a significant increase during this period, leading to a TWF and TEF increase of over 50%.

On the basis of the analysis of the F-E-W correlation, this study discusses the problem from a systemic perspective. It incorporates the findings with a collaborative governance approach and draws the following policy implications:

(1) Encourage the ecological innovation of enterprises in the tourism supply chain; invest in improving the efficiency of production and water using in food-related tourism industries; promote diversification of the tourism industry's food supply, enrich the food supply product catalog, and optimize the food consumption structure; produce food products with lower water consumption to replace replaceable food products with higher water consumption; import food necessities with high water consumption from regions surrounding mega cities, such as rice and other agricultural and sideline products with higher water consumption; strengthen the identification of water- and energy-saving enterprises in the direct tourism sector, such as restaurants and hotels, and use the saved energy and water resources for sectors with higher resource efficiency to optimize the resource allocation and improve the overall effect and further implement the process of "carbon peaking and carbon neutral."

(2) The government strengthens environmental regulations for tourism enterprises. It also introduces financial subsidies and other policies to encourage green planting, green breeding, and green production of tourism-related food products through scientific planting and mechanized operations. Deepen the structural reform on the supply side of the tourism industry, innovate water and energy saving technologies, promote the application of water and energy saving equipment in various sectors of tourism-related food supply groups, and accelerate the promotion and application of water labeling and carbon labeling products in the tourism market.

(3) Guide consumers to green consumption. During travel, choosing environmentally friendly transportation such as high-speed rail and new energy vehicles can effectively reduce the consumption of fossil energy and further reduce the consumption of water in the process of energy production. Further improve the connection between bus and metro, subway, and public bicycle in mega cities. Promoting food conservation and reducing food waste can slow down the water pressure of the food supply group. Gradually enforce the withdrawal of disposable products in hotel and restaurant from the tourism market.

The limitations of this study are as follows. The latest data on water consumption by industry in Beijing have not been released, and the water footprint accounting system needs further optimization. The study analyzed TWF and TEF, and the accounting for the food footprint of the tourism industry needs improvement. Owing to the uniqueness of the decomposition results, the reliability of the decomposition results is often questioned due to the artificial setting of a decomposition form in the research process. In the future, a dynamic SDA model with a unique decomposition form based on the time path function can be considered to improve the accuracy.

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#### **Conflict of Interest**

The authors declare no conflict of interest.

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