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Changing the industrial structure of tourism to achieve a low-carbon economy in China: An industrial linkage perspective

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ABSTRACT

By combining linkage analysis and the multi-objective programming model, this study establishes a fresh analytical framework that embeds tourism-related sectors to identify the direction of change in the structure of the tourism industry for a low-carbon economy. In a demonstration of the analytical framework, it is applied to an empirical study of China. The main results reveal that most tourism-related sectors are not key emission sectors, and that significant heterogeneity exists in the economic and emission linkage characteristics of these tourism-related sectors. In the optimal scenario, increasing the output of tourism by using the optimal production structure reduces the emission intensity of tourism and offsets macroeconomic losses caused by emission constraints. In the optimisation of the industrial structure aimed at a low-carbon economy, the direction of change in output varies across tourism-related sectors. Therefore, it is essential to avoid promoting emission reductions indiscriminately across the tourism industry. Finally, the practicality and implications of the proposed analytical framework are illustrated.

1. Introduction

As a collection of socioeconomic activities, tourism has been experiencing many external impacts and challenges, such as earthquakes, tsunamis, hurricanes, and the ongoing coronavirus (COVID-19) pandemic. However, addressing climate and environmental change by promoting energy conservation and emission reduction has always been a mid- and long-term challenge for many industries in China, including the tourism industry (Zha, He, Liu, & Shao, 2019; Sun, 2016). Against this background, many scholars and international organisations have investigated tourism carbon emissions, focusing on estimating these emissions (Lenzen et al., 2018; Meng, Xu, Hu, Zhou, & Wang, 2016; Rico et al., 2019), analysing the determinants of tourism carbon emissions (Gössling, 2009; Mishra, Sinha, Sharif, & Suki, 2019; Mishra, Sinha, Sharif, & Suki, 2019, 2019), evaluating the performance of low-carbon tourism (Tang, Zhong, & Jiang, 2018; Zha et al., 2019), and investigating basic concepts and strategies for tourism carbon emission abatement at different levels (Tol, 2007; Becken, 2013; Chiesa & Gautam, 2009; Filimonau, 2015; Sun & Higham, 2021). Attention has also been drawn to the inter-industrial linkages associated with tourism carbon emissions, because these emissions are closely related to input-output (IO) relationships between tourism and the rest of the economy (Cadarso, Gómez, Ló). Because of the inter-industrial linkages in an economy, the tourism industry cannot be regarded as a closed, independent sector, isolated from the national economy, when discussing carbon emissions embodied in the supply chain of tourism products and services (Zha et al., 2019). Promoting the low-carbon development of an economy requires knowledge of changes in the production or demand structure of tourism-related sectors from the perspective of inter-industrial linkages. Thus, to achieve the target of emission mitigation while reducing the cost of emission constraints, it is essential to identify the direction of structural changes across tourism-related sectors and thus clarify the role of each tourism-related sector in energy conservation and emission reduction from a systemic viewpoint.

As an effective technique to track carbon emission flows embodied in the supply chain, the environmental input-output (EIO) based model has been extensively used to measure direct and indirect tourism carbon emissions and to reveal the inter-industrial linkages of tourism carbon emissions (Cadarso et al., 2016; Filimonau, Dickinson, Robbins, & Reddy, 2013; Sun, 2019). Based on the application of the EIO model, scholars have carried out a series of empirical studies and proposed various ways to achieve the target of energy conservation and emission reduction in the field of tourism, including technological innovation, institutional reform, industrial changes, clean energy action plans, and consumer behaviour change (Deng, Lei, Liu, & He, 2017; Sun, Lin, & Higham, 2020; Tang et al., 2018; Zha et al., 2019). Given the fact that the potential for and costs of emissions reduction in tourism-related sectors vary greatly, scholars have suggested product or demand restructuring to promote the low-carbon transformation of the tourism industry (Sekrafi & Sghaier, 2018; Sun et al., 2020; Cocolas, Walters, Ruhanen, & Higham, 2019). However, the EIO model is always used as a purely descriptive technique, not an effective tool to guide the

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optimisation of production structure in tourism-related sectors in line with an economy's low-carbon development goals. Many questions remain regarding the direction of structural changes for tourism-related sectors. In this study, we attempt to bridge this research gap.

To this end, the present study aims to develop a fresh framework for revealing the characteristics of economic and emission linkages between sectors and identifying the direction of change in the structure of the tourism industry for a low-carbon economy. This study's two main contributions are as follows. The first contribution is that this study develops a novel methodological framework by combining the EIO-based linkage analysis and multi-objective programming model to pioneer low-carbon tourism research. By embedding tourism-related sectors into the analytical framework of industrial linkage, we can characterise the linkages of carbon emissions between sectors with economic and emission linkage indexes. Furthermore, by incorporating inter-sector carbon emission linkages into the constraints of the multi-objective programming model, the optimised production structure of tourism-related sectors aimed at supporting low-carbon economic development can be obtained from the perspective of industrial linkages. The second contribution is that by using the proposed hybrid approach, this study presents an empirical analysis for mainland China. The aim of the analysis is to reveal the characteristics of economic and emission linkages between sectors, to determine the optimised industrial structure under the guidance of a low-carbon economy and clarify the roles and responsibilities of tourism-related sectors in energy conservation and emission reduction. The remainder of this paper is structured as follows. Section 2 reviews the relevant literature. Section 3 describes the methodology. Section 4 outlines the sources and processing of data used in this study. Section 5 provides and discusses the empirical results. Finally, section 6 summarises our conclusions and proposed policy implications.

2. Literature review

2.1. Inter-industrial linkages in tourism carbon emissions

There is evidence of significant inter-industrial linkages due to the IO relationships between industries, mainly manifested as direct and indirect purchases and sales between industries or sectors (Miller & Lahr, 2001). Furthermore, accompanying the flow of goods or services between sectors is a large quantity of embodied carbon emissions, resulting from the IO relationships of intermediate goods or services (Yuan, Behrens, & Rodrigues, 2018). Thus, ignoring these carbon emissions embodied in the intermediate IO system might lead to a distorted picture of the mechanism that assigns carbon mitigation responsibilities among sectors (Huang et al., 2018).

In the literature, several methods have been adopted to research inter-industrial connections and correlations in the carbon emissions flow within an economy, including backward and forward linkage analysis (He, Reynolds, Li, & Boland, 2019; Fang & Chen, 2018; Ali, 2015), classical multiplier methods (Lenzen, 2003; Hu, Huang, Ridoutt, Yu, & Xu, 2019), sensitivity analysis (Shang, Pei, Meng, & Niu, 2016; Morán & del Río González, 2007), and the hypothetical extraction method (Deng et al., 2017; Sajid, Shahani, & Ali, 2019; Wang et al., 2013). These techniques are based on the EIO framework and aim to describe the actual status of carbon emission linkages and clarify how emissions from all industries interact (Huang et al., 2018).

As a socioeconomic activity, tourism is one of the emitters of anthropogenic carbon emissions (Dwyer, Forsyth, & Spurr, 2012). Many of tourists' consumption activities and the associated operations of supporting facilities consume a lot of energy and emit a large quantity of CO_2 (Zha et al., 2019). Additionally, many intermediate goods or services flow from other industries into the tourism industry to fulfil the consumption demands of tourists, and these also emit a significant amount of indirect carbon emissions (Munday, Tumer, & Jones, 2013). Thus, some scholars have clearly pointed out that tourism carbon emissions should be examined from the perspective of inter-industrial linkages and that only by considering these emission transfers between the tourism industry and other industries can researchers clarify the actual status of tourism carbon emissions and formulate targeted, effective strategies (Meng et al., 2016; Filimonau et al., 2013; Cadarso, Gómez, López, Tobarra, & Zafrilla, 2015; Zha et al., 2019). However, from the methodological point of view, previous studies have mainly applied the aforementioned EIO-based methods to estimate indirect or induced tourism carbon emissions and determine the inter-industrial connections and correlations with respect to carbon emissions and identified key emission sectors. Nevertheless, only descriptive analysis is used, and concerns about the optimised production structure of the tourism industry are to a large extent neglected. Thus, although existing studies have highlighted the inter-industrial linkages in tourism carbon emissions, they have not helped determine the direction of the industrial structure changes within the tourism system that would be informative in achieving a low-carbon economy.

2.2. Tourism industrial structure and low-carbon economic development

Climate change and global warming are due to the emission of greenhouse gases from the burning of fossil fuels, with CO2 emissions being the primary source of greenhouse gases (Ali, 2015). Thus, many scholars and international organisations have pointed out that immediate action is necessary to promote the transition to a low-carbon economy on a global scale (Gössling et al., 2005; Kelly & Williams, 2007; DTI, 2003; Ekholm et al., 2010). The term 'low-carbon economy' was first proposed by the British government in 2003 in a white paper entitled *Our Energy Future: Creating a Low-Carbon Economy* (DTI, 2003). As an effective way to achieve sustainable development, the low-carbon economy is a development pattern that aims to reduce energy consumption and carbon emissions while yielding high economic output, to balance economic growth and eco-environmental protection (Wang, 2011). Because the problems caused by carbon emissions are becoming increasingly severe, the low-carbon economy has been a focus of academic and political circles, and many studies on the low-carbon economy have been conducted from multi-disciplinary perspectives (Lyu, Ngai, & Wu, 2019).

As a booming industry worldwide, tourism has become one of the ways in which an economy can promote low-carbon transformation and upgrading (DTI, 2003). Nevertheless, tourism cannot be regarded as a purely 'smokeless' industry and it also has the potential to reduce its emissions (Zha et al., 2019). Many scholars and international organisations have focused on researching issues related to tourism carbon emissions; their efforts have mainly focused on the estimation of tourism carbon emissions (Dawson, Stewart, Lemelin, & Scott, 2010; Lenzen et al., 2018; Meng et al., 2016; Rico et al., 2019; Sun, 2014), analysis of the determinants of tourism carbon emissions (Gössling, 2009; Mishra et al., 2019; Tang, Wan, & Ng, 2019), performance evaluation of low-carbon tourism (Sun, 2016; Tang et al., 2018; Zha et al., 2019), and basic concepts and strategies for tourism carbon emission abatement at different levels (Becken, 2013; Chiesa & Gautam, 2009; Filimonau, 2015; Sun & Higham, 2021; Tol, 2007). Different approaches to energy conservation and emissions reduction in the tourism industry have been proposed by scholars, including technological innovation, institutional reform, industrial changes, clean energy action plans, and consumer behaviour change (Chiesa & Gautam, 2009; Sun, 2016; Zha et al., 2019). Because the potential for and cost of energy conservation and emissions reduction vary substantially by tourism-related sector, structural changes in production or demand in the tourism system have become one of the strategic options to promote the low-carbon transformation of the tourism economy (Sekrafi & Sghaier, 2018). Thus, many scholars have researched the impact of changes in the tourism industrial structure on the volume of carbon emissions or emissions intensity, for example, Moutinho, Costa, and Bento (2015); Tang, Zhong, and Ng (2017); Chen et al. (2018); Tang et al. (2017); and Sun (2016). However, such studies investigated a single tourism industry or multiple tourism-related sectors independent of one another, without considering inter-industrial linkages. Therefore, these studies, because they have ignored the industrial linkages between tourism and the remaining economy, have not provided comprehensive, systematic information on the changes in the production structure of tourism necessary for a low-carbon economy. In other words, according to the aforementioned studies, despite tremendous efforts to make structural changes to reduce emissions in the tourism system, demand for energy-intensive products in some low-carbon, tourism-related sectors might indirectly generate substantial emissions derived from energy-intensive upstream industries. Hence, we choose to analyse a tourism production structure optimised for a low-carbon economy from the perspective of industrial linkages.

2.3. Multi-objective programming approach

Multi-objective programming is an important branch of operational research and a scientific management mathematical method developed on the basis of linear programming to solve multi-objective decision-making problems (Hsu & Chou, 2000). For a detailed introduction to the multi-objective programming approach, see Gerald (1984). The literature has demonstrated that many relevant empirical studies have used this approach in various academic fields. For example, Nijkamp (1986) applied a multi-objective technique to analyse the effect of resource allocation policy while discussing relevant carbon emission reduction issues in a multi-objective programming model. Martins, Coelho, Antunes, and Clímaco (1996) proposed a multi-objective programming technique for power generation planning and demand management, to curb emissions. Hsu and Chou (2000) adopted a multi-objective programming model to assess the cost of reducing CO_2 emissions and analyse the effect of emissions abatement on the industrial structure in Taiwan. By combining multi-objective programming and a fuzzy two-stage algorithm, Ho, Chang, Wei, and Wang (2014) developed a novel programming model for energy conservation and renewable energy for campuses. Govindan and Sivakumar (2016) developed an integrated multi-objective programming approach to research issues related to the selection of the best 'green' supplier and the optimal combination of order allocation. Furthermore, in the field of tourism studies, scholars have also adopted the multi-objective programming approach to explore tourism-related optimisation. For example, with the help of the multi-objective programming approach, Li, Tang, and Li (2020) established three optimisation schemes for the tourism industry structure: the low-carbon emissions-biased scheme, growth-biased scheme, and employment-biased scheme. Rodriguez-Diaz and Pulido-Fernandez (2018) designed a multi-objective model for the problem of optimal route selection within a theme park, helping visitors in theme parks to choose an ideal route among various alternatives. In addition, in a representative work on the application of multi-objective programming approach in the field of low-carbon tourism, Sun et al. (2020) proposed an innovative analytical framework based on multi-criteria decision analysis, which can quantitatively profile the desired tourism demand mix for reducing tourism carbon emissions while balancing economic yields. Undoubtedly, the pioneering work of Sun et al. (2020) has assisted in bridging the gap in research on the optimisation of the desired market mix with the fundamental aim of promoting low-carbon tourism.

Overall, previous studies have achieved fruitful results and provided valuable references for our research. However, these studies have either focused on a purely descriptive analysis of carbon emission linkages or on the optimisation of tourism demand mix to achieve low-carbon tourism within the tourism system. It would be difficult to identify the optimal direction of structural change of economic sectors (i.e. tourism-related sectors and non-tourism-related sectors) for achieving a low-carbon economy from a systemic viewpoint; thus, the strategic positioning of the tourism industry in a low-carbon economy cannot be clarified. As such, this study aims to develop a fresh methodological framework by combining the use of EIO-based linkage analysis and a multi-objective programming model, in which we embed tourism-related sectors into the analytical framework of industrial structure optimisation within the guidelines of a low-carbon economy. This methodological framework allows us to deeply examine the inter-sectoral productive and emission linkages and to determine the optimal direction for structural changes in economic sectors necessary for a low-carbon economy. Only by comparing and analysing the structural changes of tourism-related sectors between the optimal scenario and the actual status can the roles and responsibilities of tourism-related sectors in a low-carbon economy be clarified. Finally, considering the magnitude of China's task to reduce emissions, a subsequent empirical study has been undertaken to guide policymakers in China.

3. The system boundary

Tourism is not an independent industry but a composite industry comprising multiple related sectors (Gössling, 2013). Hence, to optimise its structure from the perspective of carbon emission linkages, the academic community must clarify the scope of the tourism industry. Thus far, no consensus has been achieved on the boundaries of the tourism industry (Fong, Wong, & Hong, 2018). Scholars have tended to define boundaries on the basis of differences in their research objectives and data availability, and no unified standard has been approved in academic circles (Gössling, 2013). In the report the *Standard International Classification of Tourist Activities*, issued by the United Nations World Tourism Organization (UNWTO), tourism-related industries are divided into two categories: sectors fully affiliated with the tourism system and sectors partly affiliated with the tourism system. However, this definition is vague and thus not conducive to the definition of the scope of the tourism system because it is difficult to determine the extent to which a sector belongs to or depends on the tourism system. Furthermore, as stated in the guidance document *Tourism Satellite Account: Recommended Methodological Framework 2008* (TSA: RMF2008) published by the UNWTO, the three categories of consumption activities are tourism characteristic activities, tourism-connected activities, and other consumption activities (Sun, 2016; United Nations, 2010). Commonly, the tourism industry is regarded as a collection of those establishments whose main economic activities are the same as tourism characteristic activities (UNWTO, 2010). The classification method in the TSA: RMF2008 has been approved by many scholars and is a preferred method to use because of its clear category definition and flexible classification form.

However, the statistical accounting system for tourism is not complete, and there has not been a national Tourism Satellite Account constructed for China. In 2018, the guideline *Statistical Classification of National Tourism and Related Industries 2018* (SCNTRI2018) was released by the NBSPRC (2018). In this guideline, China's tourism industry is classified into nine categories: 1) transport, 2) food and beverage, 3) tourism accommodations, 4) sightseeing, 5) tourism shopping, 6) management and operation of tourism business (i.e. travel agencies, tourism electronic platform services, and consulting and planning services for tourism), 7) tourism entertainment, 8) support services for tourism (i.e. tourist assistance services, tourism financial services, and tourism education services), and 9) tourism-related government management services. Although this classification method aligns with the reality of China's tourism industry, it cannot be applied to our study because the nine categories differ from the sector classification in the Chinese IO table and cannot be obtained through sector adjustment. Thus, with reference to SCNTRI2018 and TSA: RMF2008, our study considers both the sector classification of the Chinese IO table for 2017 and the structural distribution of China's tourism industry and then classifies the tourism-related sectors into 18 industrial sectors: Air Transport; Road Transport; Water Transport; Railway Transport; Accommodation; Shopping; Food and Beverage services; Commercial Services;

Management of Water Conservancy, Environment and Public facilities; Culture, Arts and Recreational Activities; Sports Activities; Entertainment Activities; Information Transmission, Computer Services and Software Industry; Postal Industry; Financial Insurance Services; Leasing Services; Resident Services and Other Services; Public Management and Social Organization. Additionally, considering that each tourism-related sector contains tourism components and non-tourism components, we merge the tourism-related sectors into six major tourism-related categories (i.e. Transportation, Accommodation, Shopping, Food, Travel, and Other Tourism), with reference to the scope of consumption from the *China Domestic Tourist Expenditure Survey* compiled by the National Tourism Administration (Appendix A). Only by using the data concerning tourism expenditure can we adopt the stripping coefficient method to separate the tourism components from each major tourism-related category.

4. Methodology

The I-O model and its extended form (i.e. the EIO model) provide a powerful framework for probing into the inter-industrial linkages in terms of energy consumption and pollution emissions (Sánchez-Chóliz & Duarte, 2003). By combining this technique and the multi-objective programming approach, we can determine the characteristics of carbon emission linkages from the perspectives of economic and emission linkages and clarify the optimised tourism industrial structure for promoting low-carbon economic development.

4.1. Emission linkage analysis based on the EIO model

As Leontief (1936) initially stated, the total output of an economy can be calculated as the sum of intermediate input and final demand:

$$x = Ax + y = (I - A)^{-1} y = Ly \tag{1}$$

where x denotes the column vector ($n \times 1$) of total output; y is the column vector ($n \times 1$) of final demand; A is the matrix ($n \times n$) of direct input coefficients, whose elementa_{ij} represents the value of industry i's output directly consumed by sector j to produce one unit of output; I is an identity matrix ($n \times n$); and $\mathrm{L} = (I - A)^{-1}$is the well-known Leontief inverse matrix.

To quantify the inter-industrial linkages of carbon emissions, we can transform the standard Leontief model into the EIO model, which is given by

$$cx = c(Ax + y) = \mathrm{c}(I - A)^{-1} y = cLy \tag{2}$$

where c is defined as the row vector ($1 \times$ n) of direct emission intensity coefficients, whose element c_{ij} denotes the volume of carbon emissions per unit output; and cx represents the total carbon emissions embodied in the goods or services generated by final demand in the economy.

Similarly, we can deeply examine the relationship between output and primary input. In this regard, an alternative IO model was proposed by Ghosh (1958).

$$x^* = x^* B + v = v(I - B)^{-1} = vG \tag{3}$$

where x^* represents the row vector ($1 \times$ n) of total output (or total input); B denotes the matrix ($n \times n$) of direct output coefficients; v denotes the row vector ($1 \times$ n) of primary input; and $\mathrm{G} = (\mathrm{I} - \mathrm{B})^{-1}$ is called the Ghosh inverse matrix, within which element g_{ij} represents the total output increment of industry j driven by a unitary increase of the primary input in the industry i (Miller & Blair, 2009).

To incorporate the flow of carbon emissions into the linkage analysis, we can transform the Ghosh model into

$$x^* c' = (x^* B + v)\mathrm{c}' = v(I - B)^{-1} c' = vGc' \tag{4}$$

where c' is the column vector of direct emission intensity coefficients, which is the transposition of c; and $x^* c'$ represents the total carbon emissions embodied in the products and services driven by primary input in the economy.

On the aforementioned basis, with reference to the idea of Rasmussen (1956), we can formulate the following measurement indicators of backward and forward linkages in the productive or emission terms:

$$BL_j = \frac{\sum_{i=1}^{n} l_{ij}}{\frac{1}{n}\sum_{j=1}^{n}\sum_{i=1}^{n} l_{ij}} \tag{5}$$

$$FL_i = \frac{\sum_{j=1}^{n} g_{ij}}{\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} g_{ij}} \tag{6}$$

$$BL_j^c = \frac{\sum_{i=1}^{n} c_i l_{ij}}{\frac{1}{n}\sum_{j=1}^{n}\sum_{i=1}^{n} c_i l_{ij}} \tag{7}$$

$$FL_i^c = \frac{\sum_{j=1}^{n} g_{ij} c_j}{\frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n} g_{ij} c_j} \tag{8}$$

where BL_j and FL_i denote the backward and forward linkages with respect to inter-industrial economic flow, respectively;$BL_j > 1$ indicates that a unit increase in the final demand for industry j's economic output will produce an above-average increase in economic activities; and $FL_i > 1$ indicates that a unitary increase in the primary input into industry i will induce an above-average increase in economic activities. BL_j^c and FL_i^c represent the backward and forward linkages with respect to inter-industrial emission flows, respectively. Likewise, if $BL_j^c > 1$, a unitary increase in the final demand for industry j's economic output produces an above-average increase in carbon emissions, and if $FL_i^c > 1$, a unitary increase in the primary input of industry i generates an above-average increase in carbon emissions. Accordingly, we can classify industries from the perspective of carbon emission linkages, namely, an industry can be regarded as a key carbon emission industry if its corresponding $BL^c > 1$ and $FL^c > 1$; and if its $BL^c < 1$ and $FL^c < 1$, this industry can be defined as a non-significant carbon emission industry. We observe in this definition that key carbon emission industries have above-average emission linkages, and minor changes in these key industries would substantially affect total emissions in the economy. Conversely, changes in non-significant carbon emission industries have a non-significant impact on total emissions in an economy because of their below-average emission linkages.

Consequently, we can determine the carbon emission linkage characteristics of sectors based on their corresponding backward and forward linkage indexes in terms of pollutant emissions and economic activities. Specifically, we divide sectors (including tourism-related sectors and non-tourism-related sectors) crucial for promoting low-carbon development into two types of industrial group. If the sector is defined as a key carbon emissions sector ($BL^c > 1 FL^c > 1$) and it demonstrates weak backward and forward linkages in productive terms, we classify this sector as a member of a constrained emission group. Conversely, if the sector is defined as a non-significant carbon emissions sector and it shows strong backward or forward linkages in productive terms, we classify it as a member of an encouraged emission group. Undoubtedly, by restricting the economic output of constrained emission groups, we can achieve the goal of emission mitigation at a relatively low macroeconomic cost. Similarly, by promoting the economic output of encouraged emission groups, we can achieve the goal of economic growth at the expense of relatively low emissions. By limiting the output of industries with the characteristics of strong emission linkages and weak productive linkages (i.e. those industries in the constrained emission group), the economy can achieve maximum emissions reduction at a relatively low economic cost. Similarly, by expanding the economic scale of industries with the characteristics of weak emission linkages and strong productive linkages (i.e. those in the encouraged emission group), the economy can obtain the greatest economic output with relatively low emissions. For the remaining sectors, there is no need to impose specific constraints or settings for their structural changes, because they have little significance in promoting low-carbon development.

4.2. Multi-objective programming model

As aforementioned, changes in the tourism industrial structure should be based on a systemic perspective of an economy, and the pursuit of the optimised industrial structure in the tourism system should be aimed at achieving the low-carbon development of the whole economy, rather than the mere low-carbon development of a single tourism system. As such, to provide direction and guidance for achieving the maximum emission reduction at minimum cost to the economy, we should calculate the optimal output of industries (i.e. tourism-related industries and the remaining economy) while considering productive and emission linkages within the economic system. Low-carbon economic development does not have merely the single target of emission reduction but, more importantly, focuses balancing output growth and emission reduction (Kelly & Williams, 2007). Industrial structure adjustment is closely related to economic growth and emission reduction; economic growth and emission reduction provide, respectively, the material basis and directional guidance for industrial structure adjustment. In essence, as an effective way of sustainable development, the function of a low-carbon economy is to improve the efficiency of resource conservation and environment through the coordination and cooperation of industries; the aim is to realise the optimisation and upgrading of the industrial structure within the constraints imposed by energy conservation and emission reduction (van der Zwaan, Kober, Dalla Longa, van der Laan, & Kramer, 2018; Zhou, Zhang, & Li, 2013).

Based on the IO equilibrium relationship, this study proposes a set of hard constraints for optimising the industrial structure of an economy, which are mainly reflected in the following aspects. First, energy and carbon emission constraints require improved resource utilisation efficiency, implying reductions in energy consumption (carbon emissions) per unit of output and the control of total carbon emissions (Yan, 2017). Second, industrial group constraints should be designed to set restrictions or incentives to adjust the production proportion of specific industry groups, thereby guiding the optimisation and upgrading of industrial structure, from the perspective of industrial linkages. Third, industrial expansion or contraction constraints should be set to prevent socioeconomic chaos and shocks caused by fluctuations in the industrial system. In other words, considering the inherent regularity and inertia of industrial development, we should constrain the final demand change of each economic sector within a certain range in the short term and establish a more reliable yet still flexible fluctuation range (Chen, 2014). Under the guidance of low-carbon economic development, the two objectives of industrial structure optimisation simultaneously maximise economic output and minimise carbon emissions; that is, to balance the two objectives of economic growth and carbon emission abatement, subject to the hard energy and carbon emission constraints and those constraints applying to industry groups, industrial expansion and contraction.

4.2.1. Objective functions

As aforementioned, the objective functions of the multi-objective programming model developed in this study can be set as corresponding to the two aspects of maximising the sum of total output over sectors (z_{output}) and minimising carbon emissions (z_{emission}), as follows:

$$\max z_{output} = uL\begin{pmatrix} y^o \\ y^t \end{pmatrix} \tag{9}$$

$$\min z_{\text{emission}} = cL\begin{pmatrix} y^o \\ y^t \end{pmatrix} \tag{10}$$

where $\begin{pmatrix} y^o \\ y^t \end{pmatrix}$ is the column vector ($n\times 1$) of final demand, whose element $y_i(i = 1,\cdots,n)$ denotes the final demand of industry i, in which $y^o(\text{i} = 1,2,\cdots,\text{s})$ and y^t $(\text{i} = \text{s}+1,\text{s}+2,\cdots,\text{n})$ are the vectors of final demand corresponding to non-tourism-related sectors and tourism-related sectors, respectively; u is the $(1\times n)$ summation vector, which is used to aggregate the elements in the total output vector; c is the row vector $(1\times \text{n})$ of direct emission intensity coefficients; and L is the well-known Leontief inverse matrix.

4.2.2. Constraints

Considering the productive (emission) linkages and resource constraints within an economy and the data availability, we aim to include energy and carbon emission constraints, industrial group constraints, and industrial expansion and contraction constraints in the multi-objective programming model. Additionally, because of the practical significance of decision variables, we add the non-negative constraints' decision variables to the programming model. Finally, the corresponding constraints are set as follows:

Energy and carbon emission constraints

$$rL\begin{pmatrix} y^o \\ y^t \end{pmatrix} \le E_{\max} \tag{10}$$

$$cL\begin{pmatrix} y^o \\ y^t \end{pmatrix} \le C_{\max} \tag{11}$$

Industrial group constraints

$$\lambda_1\begin{pmatrix} y^o \\ y^t \end{pmatrix} \Big/ \lambda\begin{pmatrix} y^o \\ y^t \end{pmatrix} \le \rho_1 \tag{12}$$

$$\lambda_2\begin{pmatrix} y^o \\ y^t \end{pmatrix} \Big/ \lambda\begin{pmatrix} y^o \\ y^t \end{pmatrix} \ge \rho_2 \tag{13}$$

Industrial expansion and contraction constraints

$$\begin{pmatrix} y^o \\ y^t \end{pmatrix}^L \le \begin{pmatrix} y^o \\ y^t \end{pmatrix} \ge \begin{pmatrix} y^o \\ y^t \end{pmatrix}^U \tag{14}$$

Non-negative constraints

$$y_i{}^o \ge 0 \quad (\text{i} = 1,2,\cdots,\text{s}), y_i{}^t \ge 0 \quad (\text{i} = \text{s}+1,\text{s}+2,\cdots,\text{n}) \tag{15}$$

where r represents the row vector $(1\times \text{n})$ of direct energy consumption intensity coefficients; $E_{\max}$ represents the upper limit of the energy consumption; $C_{\max}$ represents the upper limit of the carbon emissions; λ_1 and λ_2 denote the vectors $(1\times \text{n})$ with the ith element equal to 1 and the others equal to 0, where i corresponds to an industry in the constrained industrial group or the encouraged industrial group, respectively; λ is the vectors $(1\times \text{n})$ with all the elements equal to 1 to aggregate the vector $\begin{pmatrix} y^o \\ y^t \end{pmatrix}$; ρ_1 and ρ_2 denote ratios of the final demand in the overall final demand for the constrained emission group and encouraged emission group in the base year, respectively; $\begin{pmatrix} y^o \\ y^t \end{pmatrix}^L$ and $\begin{pmatrix} y^o \\ y^t \end{pmatrix}^U$ are the lower limit and upper limit of the final demand of each sector, respectively; and corresponding industries encompass tourism-related industries and other industries.

4.2.3. Solution

Programming problems with conflicting objectives can be solved by using the goal programming technique, which minimises the deviations from the objectives, subject to the constraints included in the multi-objective programming model, instead of emphasising the absolute optimal value when making decisions and solving (Abdelaziz, 2007). When the priority and expectation value of each objective function has been determined, the original multi-objective programming model can be transformed as follows (Topaloglu, 2006):

$$\min \quad {s_1}^+ + ({s_2}^+ + {s_2}^-) \tag{16}$$

Subject to

$$uL\begin{pmatrix} y^o \\ y^t \end{pmatrix} + \frac{1}{w_1}{s_1}^- - \frac{1}{w_1}{s_1}^+ = G_{output}$$

$$cL\begin{pmatrix} y^o \\ y^t \end{pmatrix} + \frac{1}{w_2}{s_2}^- - \frac{1}{w_2}{s_2}^+ = G_{ce}$$

$$rL\begin{pmatrix} y^o \\ y^t \end{pmatrix} \le E_{\max}$$

$$cL\begin{pmatrix} y^o \\ y^t \end{pmatrix} \le C_{\max}$$

$$\lambda_1\begin{pmatrix} y^o \\ y^t \end{pmatrix} \Big/ \lambda\begin{pmatrix} y^o \\ y^t \end{pmatrix} \le \rho_1$$

$$\lambda_2\begin{pmatrix} y^o \\ y^t \end{pmatrix} \Big/ \lambda\begin{pmatrix} y^o \\ y^t \end{pmatrix} \ge \rho_2$$

$$\begin{pmatrix} y^o \\ y^t \end{pmatrix}^L \le \begin{pmatrix} y^o \\ y^t \end{pmatrix} \ge \begin{pmatrix} y^o \\ y^t \end{pmatrix}^U$$

$$y_i^o \ge 0 \quad (i = 1, 2, \cdots, s), y_i^t \ge 0 \quad (i = s+1, s+2, \cdots, n), {s_k}^+ \ge 0, {s_k}^- \ge 0$$

where G_{output} is the objective of economic development; G_{ce} is the objective of emission abatement; w_1 and w_2 are the weighting factors for${s_1}^-({s_1}^+)$and ${s_2}^-({s_2}^+)$, respectively, denoting the priority levels of G_{va} and G_{ce}, respectively; ${s_1}^+$ and ${s_1}^-$ denote the positive and negative deviation variables for the goal of economic development, respectively; and ${s_2}^+$ and ${s_2}^-$ represent the positive and negative deviation variables for the goal of carbon emissions, respectively. Additionally, in the objective function, we minimise the positive deviation of the goal of economic development (${s_1}^+$), indicating that this programming model aims to satisfy$z_{output} \ge G_{va}$; we also minimise ${s_2}^+$ and ${s_2}^-$, indicating that this model aims to satisfy $z_{emission} = G_{ce}$. For details on the setting of positive or negative deviation variables in the objective function, refer to Foued and Sameh (2001).

5. Data sources and processing

5.1. Non-competitive IO tables

Due to the limited availability of IO data, our study is based on the most recently available Chinese IO table: that for 2017. However, the IO tables compiled by the National Bureau of Statistics are competitive IO tables, in which both intermediate input and final demand consist of imported and domestically produced goods. Because the main purpose of this study is to determine the optimal tourism industrial structure from the perspective of inter-industrial carbon emission linkages, rather than the perspective of those carbon emission linkages between countries embodied in international trade, research based on the competitive IO table containing imported goods is beyond the scope of our work. For these reasons, we should exclude imported products from the intermediate input and the final demand when measuring the inter-industrial carbon emission linkages of a single open economy. Otherwise, the carbon emissions flow embodied in the supply chain will probably be overestimated.

To avoid such overestimation, we employ the approach proposed by Minx et al. (2011) to transform the competitive IO table into a non-competitive IO table. Following the import proportionality assumption widely used by Organization for Economic Co-operation and Development (OECD) countries for establishing import goods flow tables, this study first assumes that the share of imports in intermediate input and final demand (excluding exports) for each industry is the same as the average share of imports in the corresponding sector's total output and then subtracts the imported products from the intermediate input and final demand of each industry, per those proportional data. The details of this method are in Weber, Peters, Guan, and Hubacek (2008).

5.2. Industrial merger of IO tables

To ensure that the sectoral classification of Chinese IO table for 2017 matches relevant energy statistics data (Chen & Zhang, 2010), we merge the 149 industries of this IO table in accordance with the Classification Standards and Codes of National Economy Industry (NBSPRC, 2017). Finally, we obtain a new Chinese IO table for 2017, which covers 18 tourism-related sectors and 33 other sectors (Appendix B). Additionally, because each tourism-related sector contains both tourism and non-tourism components, we can combine the optimal results of the 18 tourism-related sectors into six major tourism subsectors and then employ the stripping coefficient method developed by Meng et al. (2016) to exclude non-tourism components, determining the optimal direction for structural changes in the tourism industry. Data concerning travel expenditure structure for the stripping calculation are from the *China Domestic Tourist Expenditure Survey* compiled by the National Tourism Administration of mainland China.

5.3. Energy consumption and carbon emissions data

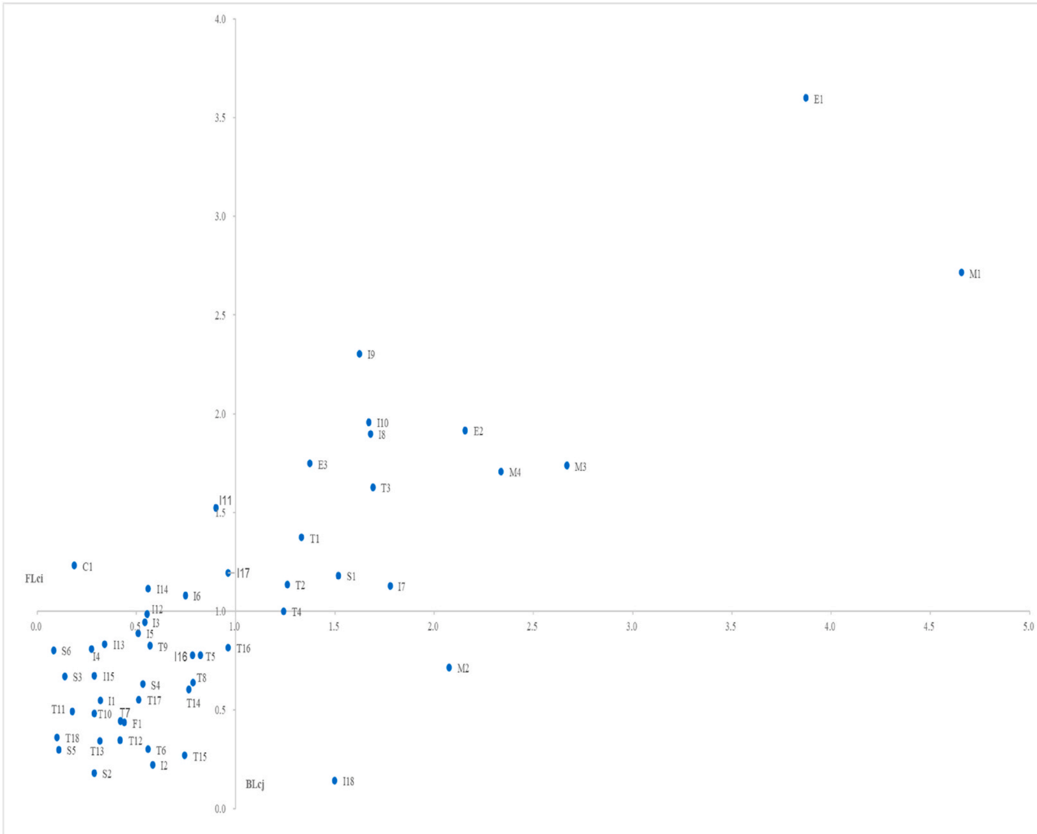
In this study, the direct energy consumption and carbon emissions for each sector is estimated by using the *Chinese Energy Balance Sheet* and Chinese IO table for 2017. We first estimate the weighted-average energy price by using the ratio of the sum of the monetary value of energy sources, as an intermediate input in the IO table, to the corresponding physical quantities of these energy sources derived from the energy balance sheet. Next, the direct energy consumption of each industry is calculated by dividing the monetary value of energy consumed by this industry in the IO table by the weighted-average price of the energy (for details, see Park & Heo, 2007). Accordingly, we utilise the emission factors of energy from the *Intergovernmental Panel on Climate Change Guidelines* (IPCC, 2006) to calculate the direct carbon emissions. Finally, by dividing the direct energy consumption (direct carbon emissions) of each industry by the total output of the corresponding industry, we can obtain the direct energy consumption intensity coefficients (direct carbon emission intensity coefficients) for all sectors.

6. Results and discussion

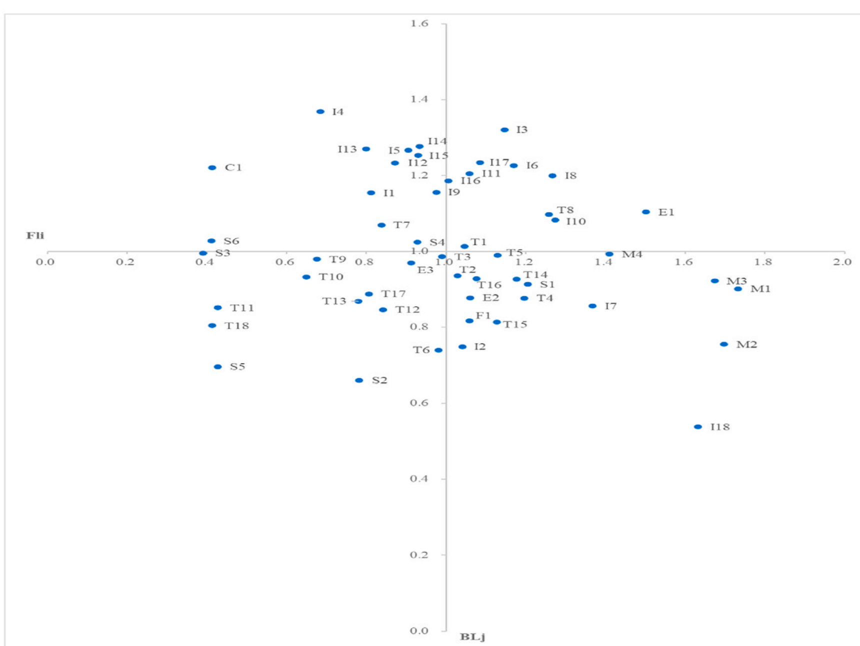
Based on the backward and forward linkage indexes in emissions and economic terms, and the classification criteria for constrained emission groups and encouraged emission groups, Section 6.1 presents the linkage characteristics of tourism-related sectors and other sectors in mainland China. By embedding tourism-related sectors into the analytical framework of industrial linkage, Section 6.2 aims to obtain the optimised industrial structure of the Chinese economy by applying a combined use of the EIO-based linkage analysis and multi-objective programming model, which can provide important guidance for identifying the direction of change in the output of tourism-related sectors needed for a low-carbon economy and clarify the roles and responsibilities of tourism-related sectors in the low-carbon economy.

6.1. Analysis of the linkage characteristics of tourism-related sectors and other sectors

In Fig. 1, subgraph (a) and subgraph (b) present the backward (forward) industrial linkages in carbon emissions and economic terms, respectively, and both subgraphs show forward linkages on the horizontal axis and backward linkages on the vertical axis. As such, we can



(a)



(b)

Fig. 1. Backward and forward linkages in terms of carbon emission and economic flows.

determine which groups those sectors belong to, further clarifying their emission linkage characteristics.

In subgraph (a), the economic sectors M1, M3, M4, I7, I8, I9, I10, E1, E2, E3, T1, T2, T3, T4, and S1 are in the first quadrant, with above-average emission linkages. Most heavy industrial sectors with energy and mineral resources as main inputs are typical key emission sectors, and the key emission sectors in the tourism system are mainly concentrated in the transport field. Various tourism transport modes have become the core sources of carbon emissions flow embodied in the tourism production system because of their significant backward and forward linkages in carbon emissions terms. This finding is consistent with those of, for example, Sajid, Li, and Cao (2019), Lenzen (2003) and Wen and Wang (2019), although subtle differences exist because of their differing sectoral classification criteria. As depicted in the third quadrant of subgraph (a), non-significant emission sectors, with below-average emission linkages, are widely distributed in the primary, secondary, and tertiary industries, although the vast majority of these sectors are in the tertiary industry category. Most of the tourism-related sectors have relatively weak forward and backward linkages, with below-average values, such as Accommodation (T5); Shopping (T6); Food and Beverage services (T7); Management of Water Conservancy, Environment and Public facilities (T9); Culture, Arts and Recreational Activities (T10); Sports Activities (T11); Entertainment Activities (T12); Information Transmission, Computer Services and Software Industry (T13); Postal Industry (T14); Financial Insurance Services (T15); Leasing Services (T16); Resident Services and Other Services (T17); and Public Management and Social Organization (T18), which are typical non-significant emission sectors. Therefore, except for transport, all tourism-related sectors are non-significant emission sectors with below-average emission linkage values. Additionally, the findings reveal that the forward and backward emission linkages of the tourism industry are 0.836 and 0.766, respectively, demonstrating that most tourism-related sectors are not key emission sectors. This finding supports the result derived from Tang et al. (2018), who found that tourism activities have the highest direct and total energy efficiencies and carbon efficiencies, and that the tourism industry is not a priority for energy conservation and emission reduction compared to other industries, especially manufacturing industries. In this sense, from a systemic perspective, not all tourism-related sectors should be the focus of energy conservation and emission reduction in any low-carbon development strategy. Most studies, for example, Chiesa and Gautam (2009), Filimonau (2015), Cadarso et al. (2015), Tang et al. (2017), and Zha et al. (2019), have been limited to exploring tourism-related emissions from a tourism system perspective, which might overemphasise the responsibility of the tourism industry to reduce emissions and fail to clarify the differences in roles between tourism-related sectors in low-carbon economic development.

As shown in Table 1, sectors in the constrained emission group, such as M1, M3, M4, I7, I9, E2, E3, S1, T2, T3, and T4, are key emission sectors with a relatively weak pulling effect (driving effect) on upstream output growth (downstream output growth). These constrained emission group sectors are the key nodes that play the role of 'connecting the preceding and the following' in the carbon emission flows embodied in the supply chain, but without playing a similar role in the economic or productive flows embodied in the supply chain. Therefore, to achieve the low-carbon development target, it is essential to limit the expansion of these constrained emission group sectors in traditional and non-green development patterns and restrain the embodied emission flows originating in these sectors. Conversely, as described in Table 1, sectors in the encouraged emission group, including 6 tourism-related sectors and 12 non-tourism-related sectors, are non-significant emission sectors with a relatively strong pulling or driving effect on output growth. These encouraged emission group sectors are not pivotal links that transfer carbon emissions flows in the industrial network, but they do have a significant positive impact on output growth through their industrial linkages. Hence, given the current level of technology and energy structure, the economic scale of these sectors should be allowed to expand with traditional development patterns, thereby offsetting the loss of output from more stringent emission constraints on the constrained group sectors. Although promoting the development of the encouraged group sectors in traditional development patterns would increase direct and indirect emissions, the magnitude of the increase is much smaller than the corresponding reduction in emissions in the constrained group sectors. Regarding the tourism system, Accommodation (T5), Food and Beverage services (T7) and Commercial Services (T8), Postal Industry (T14), Financial Insurance Services (T15), and Leasing Services (T16) belong to the encouraged emission group with below-average carbon emission linkages. These sectors exert a strong forward or backward linkage effect on the economy. The development of these tourism-related sectors should therefore be supported such that the economic slump due to the emissions abatement of constrained emission group sectors (e.g. by elimination of obsolete production capacity, production stoppages, and more stringent environmental inspection) can be counteracted to some extent, compensating for the economic losses caused by strengthening the emission constraints on the high-energy consumption and high-emission sectors. Through comparative analysis, it can be found that for the tourism industry, the final demand ratio of the constrained group to the encouraged group is 1:1.72 and that the corresponding final demand ratio reaches 1:10.05 for the whole economy, indicating that the encouraged emission group maintains the bulk of the tourism system or the whole economic system.

6.2. *Analysis of calculation results regarding industrial structure optimisation*

The analysis of inter-industrial linkage in productive and emission

Table 1
Constrained and encouraged emission groups and their final demands in mainland China (100 million Yuan).

Sector number	Constrained emission group	Encouraged emission group	Sector number	Constrained emission group	Encouraged emission group
F1		29463.46	E2	1887.89	
M1	334.18		E3	1016.77	
M3	65.39		T4	1324.19	
M4	131.68		S1	2751.29	
I1		61339.84	S4		6846.51
I2		3135.31	S6		41440.28
I3		6931.38	T2	17641.88	
I4		24213.87	T3	2635.75	
I5		9011.44	T5		1348.43
I7	4328.64		T7		15236.35
I9	3411.14		T8		8165.88
I12		37345.39	T14		1491.99
I13		46311.09	T15		21689.21
I15		39279.95	T16		222.89
I16		3655.02			

terms can provide insights into the prospective direction of structural changes. What follows next is the identification of potential solutions, thereby clarifying the role of tourism-related sectors in a low-carbon economy within the given current energy mix, management capacity, and technical level of the industry. Herein, to solve the multi-objective programming model presented in the methodology section, the goal programming technique is adopted to solve the aforementioned programming problem. In addition, considering that the essence of a low-carbon economy is to balance the two objectives of economic growth and carbon mitigation, we assume that promoting economic growth and reducing carbon emissions are equally important.

For the objective functions and constraints included in the proposed multi-objective programming model, the relevant settings are as follows. First, we set the actual total output in 2017 as the goal of economic growth, indicating that the total economic output should be as close as possible to its level in 2017. Second, considering that the development of a low-carbon economy is equivalent to minimising carbon emissions, under the premise of a given economic output, we set different emission reduction scenarios against 10 emission reduction rates (1 %, 2 %, 3 %, 4 %, 5 %, 6 %, 7 %, 8 %, 9 %, and 10 %) and, under these different emission reduction scenarios, the goals of energy conservation and emission abatement are set as the potential energy consumption and carbon emissions level, on the premise that the corresponding emissions reduction rate could be achieved. Third, the demand for a sector's products or services is subject to inertia in the short term, which dictates that the corresponding final demand should fluctuate within a reasonable range; otherwise, disruptions in the economic system could easily occur (Hsu & Chou, 2000; Scherer, 1996). With reference to Scherer (1996), we set the upper and lower limits of the final demand fluctuation of each sector at a 15 % expansion and 15 % contraction, respectively. By setting this constraint, excessive fluctuations in the final demands of various sectors can be prevented, thus conforming to the reality of China's end-use applications and markets. Finally, according to the calculation results of constrained and encouraged industrial groups, we take the actual production proportion of the constrained emission group (0.0383) and that of the encouraged emission group (0.3846) as the upper limit of the constrained emission group and the lower limit of encouraged emission group in the industrial group constraints, respectively.

In Fig. 2, with the increase in the emission reduction ratio, the optimal total output continues to decrease. With the current energy structure and level of technology, the increasing emission reduction ratio suggests that the key areas of energy conservation and emission reduction would gradually extend from 'Low-Cost and High-Potential' sectors to 'High-Cost and Low-Potential' sectors and that the constraints imposed by energy conservation and emission reduction on the macro economy have been continually strengthened, leading to an increase in macroeconomic costs (Hsu & Chou, 2000). Therefore, it can be inferred that given the current IO relationships between sectors, the maximum emission reduction ratio that can be achieved without reducing the total output is 5 %, and the corresponding emission reduction would amount to 110,214,143.01 tons. Overall, 5 % is a suitable emission reduction ratio for the Chinese economic system.

As shown in Fig. 3, with the goal of reducing carbon emissions by 5 %, 28 sectors would need to decrease their total output. Sectors with the largest decrease in total output mainly cover I8, I9, I10, M1, and I7. Considering the inter-sectoral production and emission linkages, sectors that need to reduce their total output are not limited to the constrained emission group, and a drastic decline in the total output of constrained emission group sectors would inevitably have a negative impact on the total output of other sectors (Qi & Peng, 2019). To avoid, as far as possible, impeding economic growth, policy makers could promote the development of some sectors with no or weak emission constraints, especially encouraged emission group sectors, to increase the total output of the whole economy with relatively lower emissions and offset the macroeconomic losses caused by the emission constraints in the aforementioned 28 sectors, balancing between economic growth and carbon emission mitigation. Specifically, compared with the current output level of sectors within the economy, 23 sectors in the optimised production structure would need to increase their total output. Sectors that need the largest increase in output are mainly in the encouraged emission group and include Agriculture, Forestry, Animal Husbandry and Fishery (F1); Food manufacturing (I1); Textile manufacturing (I3); Manufacture of Textile, Apparel, Shoes, Hats, Leather, Down and Related Products (I4); Transportation Equipment Manufacturing (I13); Communication Equipment, Computer and Other Electronic Equipment Manufacturing (I15); and Education (S5) (Fig. 3). Therefore, the results further reveal that to promote a low-carbon economy, efforts to save energy and reduce emissions should focus on industrial groups instead of separate key emission sectors, and that a balance between emissions reduction and economic growth can be achieved through cross-sectoral cooperation and coordination.

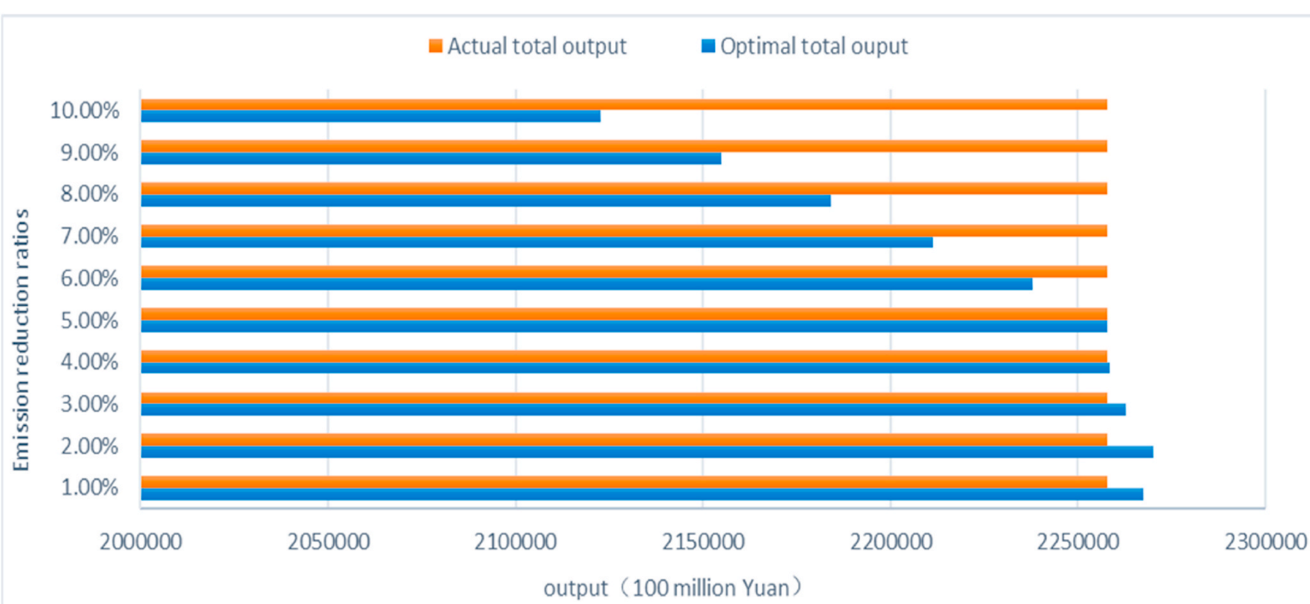


Fig. 2. The optimal total output under different emission reduction scenarios and the corresponding actual output in 2017.

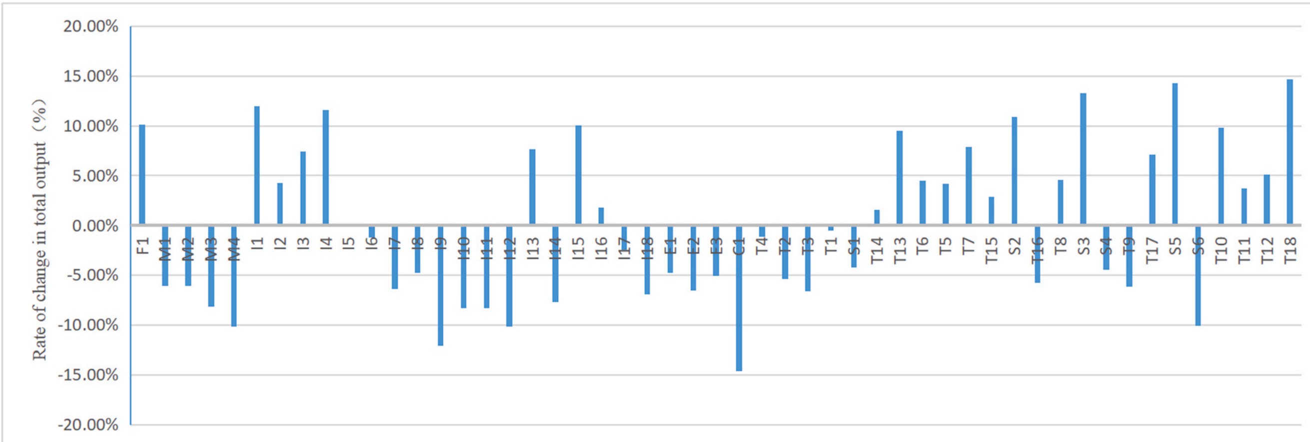


Fig. 3. Changes in the total output of tourism-related sectors and non-tourism-related sectors under the optimal scenario.

For tourism-related sectors, compared with the current production structure of China's economy, some tourism-related sectors should reduce their total output to achieve the optimal production structure; these include Air Transport (T1); Road Transport (T2); Water Transport (T3); Railway Transport (T4); Management of Water Conservancy, Environment and Public facilities (T9); and Leasing Services (T16); their outputs need to be reduced by 0.55 %, 5.41 %, 6.63 %, 1.12 %, 6.15 %, and 5.78 %, respectively. By contrast, other sectors need to increase their total output; these include Accommodation (T5); Shopping (T6); Food and Beverage services (T7); Commercial Services (T8); Culture, Arts and Recreational Activities (T10); Sports Activities (T11); Entertainment Activities (T12); Information Transmission, Computer Services and Software Industry (T13); Postal Industry (T14); Financial Insurance Services (T15); Resident Services and Other Services (T17); and Public Management and Social Organization(T18); their outputs need to be raised by 4.16 %, 4.46 %, 7.91 %, 4.53 %, 9.82 %, 3.76 %, 5.09 %, 9.52 %, 1.59 %, 2.88 %, 7.11 %, and 14.63 %, respectively. Hence, with the current inter-sector IO relationships in both economic and emission terms, the development of most tourism-related sectors without emission constraints would help offset the macroeconomic losses caused by strengthening the emission constraints for specific groups, which in turn would be beneficial to the whole national economy in achieving a balance between economic growth and emission reduction.

Furthermore, by adopting the coefficient stripping method, we can further separate non-tourism components from each tourism-related sector, to compare and analyse the structural changes of the six tourism subsectors and their corresponding impact on economic output and emissions given the current IO relationship within the economic system. As shown in Fig. 4, compared with the current output level, the tourism industry needs to increase its total output by 3.18 % under the optimal scenario with a corresponding increase of RMB 183.110 billion. Based on the specific details of each tourism subsector, the total output of tourism transport needs to be reduced by 4.57 %, while those of Accommodation, Shopping, Food, Travel, and Other Tourism need to increase by 4.16 %, 4.46 %, 7.91 %, 3.23 % and 7.49 %, respectively. Within these tourism subsectors, Management of Water Conservancy,

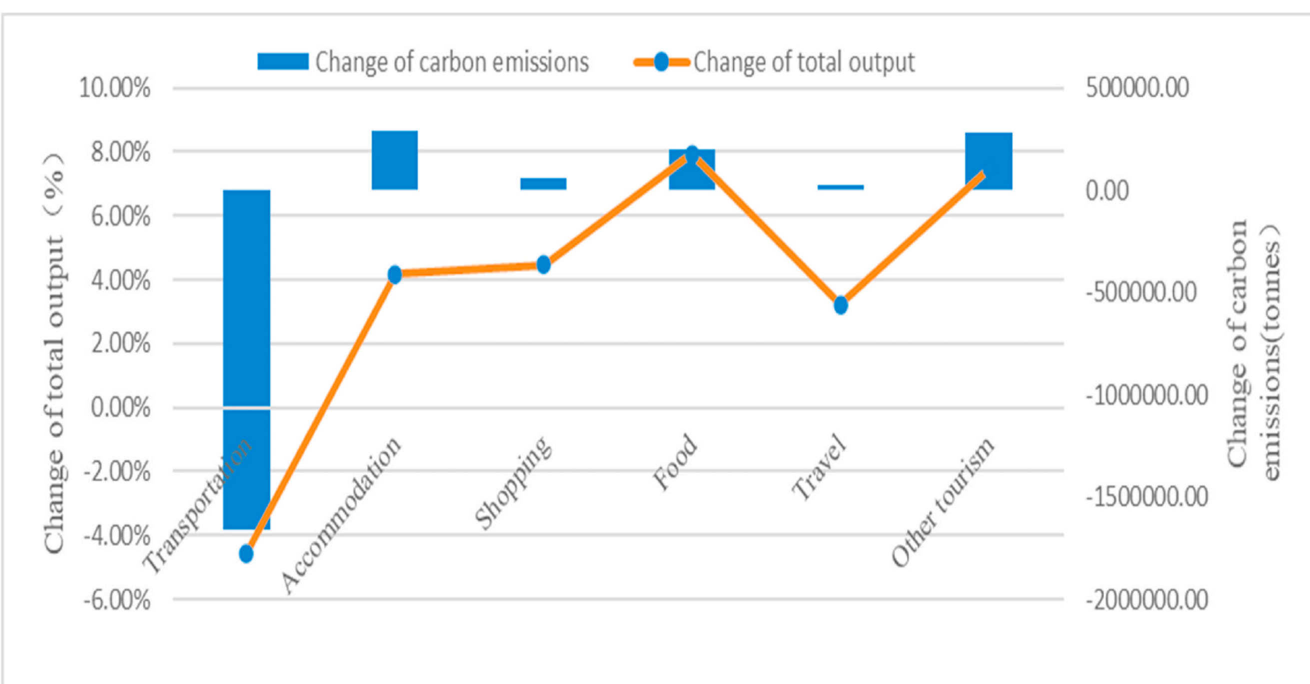


Fig. 4. The rate of increase or decrease in the total output of tourism components under the optimal scenario, and the corresponding changes in carbon emissions.

Environment and Public facilities (T9) in Travel, and Leasing Services (T16) in Other Tourism, need to decline by 6.15 % and 5.78 %, respectively. Although the total output of the tourism industry needs to be increased under the optimal scenario, its total carbon emissions would accordingly decrease by 1.57 %; a decrease of 802,700 tons. Therefore, we are not surprised that tourism can not be regarded as a priority for energy conservation and emission reduction in the low-carbon development strategy proposed in this study, especially for mainland China, a major industrial country on a global scale (Zha, Fan, Yao, He, & Meng, 2020). Obviously, this finding significantly differs from those of most studies, for example, Meng et al. (2016); Xiao, Yu, and Wang (2011); Zha, Shu, Li, and He (2017); Wang, Shao, Zhou, and Liu (2017); and Zhang and Chen (2010); which have suggested that energy conservation and emission reduction should be implemented in all segments of the tourism industry. Furthermore, previous studies have found that tourism generates higher emissions per unit of economic output than the national average; thus, a strong carbon mitigation effort is required (Lenzen et al., 2018; Dwyer, Forsyth, Spurr, & Hoque, 2010; Sun & Higham, 2021; Sun, 2014). Fig. 5 presents the direct carbon emission intensity values by sector in 2017. As can be seen from Fig. 5, the average direct carbon emission intensity across all sectors reached 0.098 tons/10^4 Yuan, and most of the sectors with above-average direct carbon emission intensity are concentrated in the secondary industry and transportation. In addition, at the subsector level, all tourism-related sectors, with the exception of transport, are among those with below-average emission intensity values. However, it can be found that if we regard tourism as a separate industry, its corresponding direct carbon intensity is slightly above the national average, reaching 0.100 tons/10^4 Yuan. Moreover, the calculation results show that the amount of direct carbon emissions from the tourism industry reached 54,202, 435.12 tons in 2017, accounting for 2.46 % of national total carbon emissions. Compared with previous studies, the calculation results of this paper are basically consistent with the findings of related studies based on the top-down estimation method, such as Shi (2015), Meng et al. (2016) and Zha et al. (2020). By contrast, the share of carbon emissions from tourism in total emissions is significantly larger than the estimation results of related studies based on the bottom-up estimation method. The possible reason lies in the differences between bottom-up and top-down estimation methods. As noted by Sun (2014) and Meng et al. (2016), the bottom-up approach is best suited for small regions, but it tends to underestimate the carbon emissions of different sectors within the tourism industry. Additionally, a further comparison of tourism with other sectors shows that the tourism industry ranks relatively high among all sectors in terms of aggregate carbon emissions, with M1, I8, I9, I10, E1, C1 ahead of it. Furthermore, it is evident from this study that indirect carbon emissions contribute more to total carbon emissions than direct carbon emissions and account for 64.72 %, implying that most of the carbon emissions associated with tourism come from intermediate production processes. This finding also echoes the conclusions stated by Becken and Patterson (2006), Dwyer et al. (2010), Meng et al. (2016), and Zha et al. (2020). As such, without considering the synergistic and collaborative strategies between sectors proposed in this paper, energy conservation and emission reduction in the tourism industry cannot be ignored.

By contrast, differences in low carbon development strategies have led to different strategic positioning of tourism-related sectors, which yields seemingly contradictory conclusions in this study. The aforementioned literature focuses on a single tourism system and emphasizes the fact that the aggregate emissions from tourism are relatively large. Conversely, the results of this paper demonstrate that there are significant differences in the characteristics of carbon emission linkages among tourism-related sectors, and that most tourism-related sectors do not belong to a constrained emission group with strong emission linkages and weak production linkages, which thus can play different roles in achieving the low-carbon development goals of an economy through cross-sectoral cooperation and coordination. Specifically, by strengthening emission constraints on the constrained emission groups and facilitating the development of the encouraged emission groups in

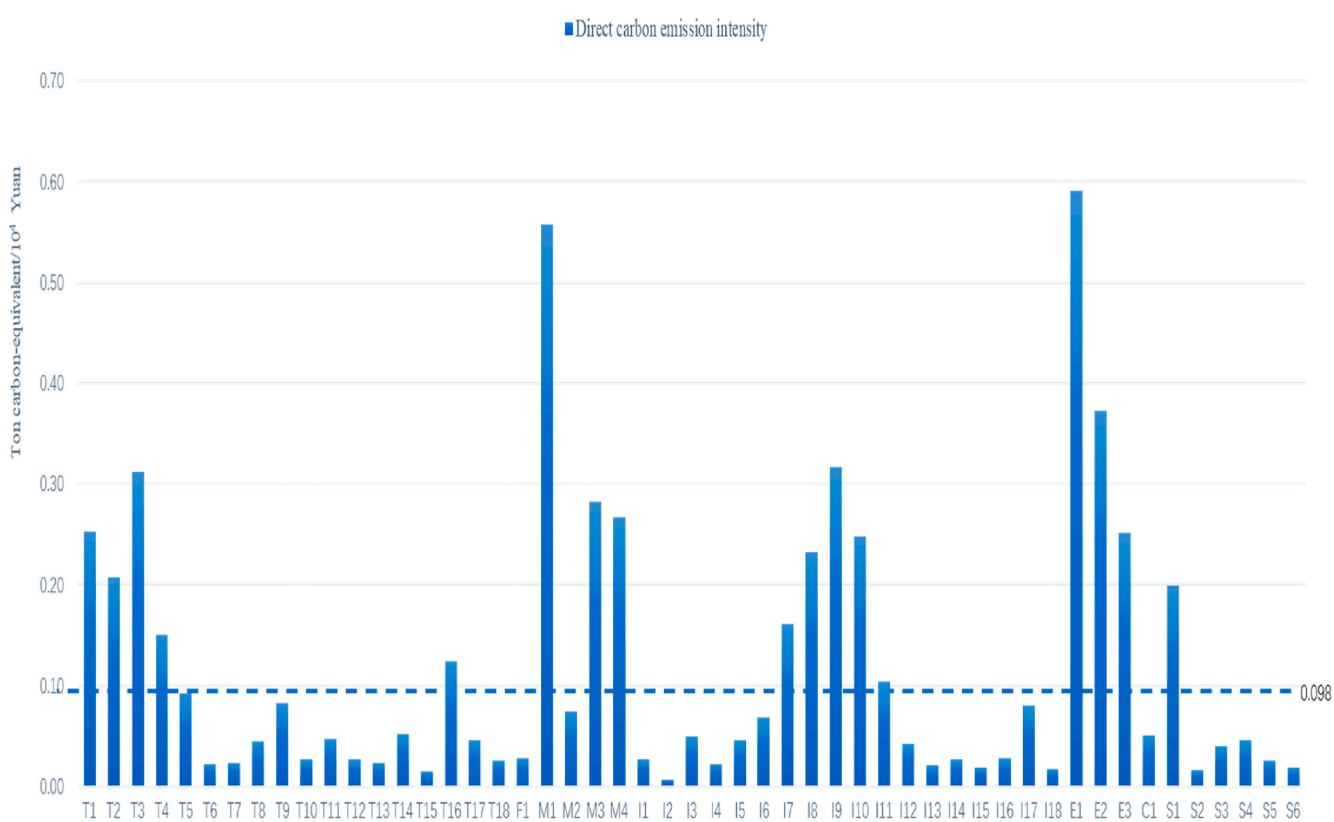


Fig. 5. Direct carbon emission intensity of tourism-related sectors and non-tourism-related sectors.

accordance with traditional development patterns, the Chinese government can balance output growth and emission reduction from a systemic viewpoint. In a sense, we can view most tourism-related sectors as part of the key economic sectors that ensure sustained economic growth, while imposing carbon emission constraints on key constrained group sectors (e.g., Mining and Washing of Coal, Mining and Processing of Metal Ores, Petroleum Processing, Coking and Nuclear Fuel Processing), thereby allowing the entire national economic system to maintain economic growth while achieving emission reduction targets. Nevertheless, we should also note that the amount of direct carbon emissions from tourism reached 14,257,328.45 tons, 17,867,209.89 tons, 32,682,677.83 tons, and 54,202,435.12 tons in 2002, 2007, 2012, and 2017, respectively. The sharp rise in direct carbon emissions from tourism, especially after 2007, was due to the expansion in economic scale caused by the rapid development of tourism. If the average intensity of tourism carbon emissions remained constant since 2002, the direct carbon emissions from tourism in 2017 could reach 94,136,452.9 tons. Therefore, scholars believe that there is considerable room for carbon reduction due to the large scale and relatively high intensity of tourism carbon emissions. Unlike previous research, this paper argues that tourism-related sectors could play different roles in low-carbon development. Theoretically, the successful implementation of the above-mentioned low-carbon development strategy presupposes good coordination among economic sectors within the economy. Otherwise, it may be difficult to strike a balance between economic growth and emission reduction. Therefore, the optimisation results are limited to proposing to policy maker an optimised tourism industrial structure based on the current IO equilibrium relationship and demonstrating the priorities for energy conservation and emission reduction among economic sectors within the economic system, especially within the tourism system.

Besides, our calculation results also indicate that the structural adjustment of tourism should focus on the coordination and cooperation of sectoral groups, rather than be limited to a single tourism system. Guided by the low-carbon development target for the whole economy, the government should clarify the differences in the roles of tourism-related sectors in energy conservation and emission reduction and determine the differentiated responsibilities of tourism-related sectors from a systemic perspective. Specifically, given the current IO relationships within the economy, tourism-related sectors, such as Transportation, and Management of Water Conservancy, Environment and Public facilities (T9) in Travel and Leasing Services (T16) in Other Tourism, should be required to conduct low-carbon transformation and upgrading even if they have to suffer economic losses from increased emission constraints. Conversely, the remaining tourism-related sectors, which account for the vast majority of the tourism industry, could be allowed to develop in their traditional development patterns.

7. Conclusions and policy implications

By combining the EIO-based linkage analysis and multi-objective programming approach, this study develops a fresh methodological framework from the perspective of inter-industrial linkages to identify key carbon emission sectors and the optimised tourism industrial structure with respect to emission reduction targets in an economy. Based on the proposed combined linkage analysis and multi-objective programming approach, we determine the characteristics of inter-industrial carbon emission linkages with economic and emission linkage indexes and further incorporate these characteristics into the constraints of a multi-objective programming model, comparing and analysing the structural changes of tourism-related sectors between the optimal scenario and the current situation. Subsequently, the proposed methodological framework is applied to the Chinese economy as an example, to determine the direction of structural changes across tourism-related sectors and thus balance economic growth and emissions mitigation from a systemic viewpoint. Results show that:

(1) Significant differences between sectors exist in their economic and carbon emission linkages, which provide a foundation for their division into constrained and encouraged emission groups and the clarification of their carbon emission linkage characteristics. Results reveal that, except for the transportation sector, tourism-related sectors are all non-significant emission sectors. The results of key emission group division show that the encouraged emission group occupies a dominant position in the production structure of China's tourism economic system. For the tourism-related sectors, Accommodation (T5), Food and Beverage Services (T7), Commercial Services (T8), Postal Industry (T14), Financial Insurance Services (T15), and Leasing Services (T16) are typical sectors in the encouraged emission group. while Railway Transport (T4), Road Transport (T2), and Water Transport (T3) are key emission sectors with weak productive linkages in the constrained emission group.
(2) The optimisation results show that given an economy-wide target of reducing carbon emissions by 5 %, energy conservation and emission reduction efforts should not be limited to a single economic sector, and that more focus should be on the sectoral groups with similar productive and emission linkage characteristics. As such, policy makers should focus on the coordination and cooperation between tourism-related sectors and non-tourism-related sectors in energy conservation and emission reduction, and consider the low-carbon development of the whole economy as a target from a systemic perspective. For tourism-related sectors, given the current IO relationships within the Chinese economy, most tourism-related sectors could boost their sectoral economies in conventional development patterns, except for Air Transport (T1), Road Transport (T2), Water Transport (T3), Railway Transport (T4), Management of Water Conservancy, Environment and Public facilities (T9), and Leasing Services (T16), to offset the macroeconomic losses caused by energy conservation and emission reduction in some key sectors, especially sectors with high-energy consumption and high emissions.
(3) In the optimal scenario, the rates of increase or decrease in the total output of six major tourism components vary by sector, and the tourism industry needs to increase its total output by 3.18 %, an increase of 183.11 billion yuan. Given the current IO equilibrium relationships, most tourism-related sectors should not be regarded as a priority for energy conservation and emission reduction, especially for mainland China, a major industrial country on a global scale, and significant heterogeneity exists in the economic and emission linkage characteristics of its subsectors. With reference to the optimised production structure, differentiated efforts to promote emissions reduction and economic development among tourism-related sectors (i.e. strengthening the emission constraints on the transport sector and relaxing those on Accommodation, Shopping, Food, Travel, and Other Tourism) would not only be beneficial for reducing the emissions intensity of the whole tourism industry, but also for offsetting macroeconomic losses caused by energy conservation and emission reduction in other industries, assisting in the development of a low-carbon economy.

From the perspective of policy, the analytical framework proposed by this study can provide valuable information to and directional guidance for policymakers in formulating feasible, practical tourism policies in the context of a low-carbon economy. First, by comparing the differences in production structure between the optimal scenario and the current situation, we observe that the roles and responsibilities of tourism-related sectors in the low-carbon economy should be clarified by taking a systemic perspective rather than a single tourism perspective, and that given the current energy mix, management capacity, and technical level of the industry, the Chinese government should promote the development of tourism-related sectors with differentiated emission constraints, to compensate, to some extent, for the economic losses caused by abating the emissions of the high-energy consumption and high-emission sectors, thereby balancing economic growth and emission mitigation. In other words, the Chinese government could focus on energy conservation and emission reduction in some constrained group sectors, especially sectors with high energy consumption and high emissions, while easing the emission constraints on tourism-related sectors other than transport. This finding significantly differs from those of most studies (e.g. Meng et al., 2016; Xiao et al., 2011; Wang et al., 2017; Zha et al., 2017; Tang et al., 2017), and the countermeasures of energy conservation and emission reduction proposed in these studies are for the entire tourism industry. The possible reason is that this paper embeds tourism-related sectors into the entire national economic system and seeks to solve for the optimised industrial structure with the goal of balancing economic growth and emission reduction for the entire national economic system, rather than focusing on the low-carbon development of a single tourism system. Second, the structural interdependence of an economy indicates that understanding the inter-industrial linkages in productive and emission terms is a prerequisite for clarifying the roles and responsibilities of tourism in a low-carbon economy (Zha et al., 2020). It also suggests that the Chinese government could scrutinise the role or responsibility of tourism-related sectors in energy conservation and emission reduction from a systemic perspective and thus achieve emission reduction targets through coordination and cooperation between sectoral groups. Concretely, the Chinese government could weaken the emission constraints of most tourism-related sectors and reduce the cost of emission constraints, thereby offsetting the macroeconomic losses caused by controlling energy consumption and eliminating obsolete production capacity in some sectors with high energy consumption and high emissions. Finally, although we have taken full account of the IO equilibrium relationship among sectors in solving for the optimal industrial structure, we should note that the tourism industrial structure is predetermined by factors such as institutional environment, cultural background, resource endowments, consumer preferences, income levels, economic development, etc. (Ghosh, 2020; Sun et al., 2020; Tang et al., 2017; Zha et al., 2020). It is not possible to forcibly match the current tourism industrial structure to the optimal values without considering the subjective and objective conditions within the economic system. Only by relying on the local context and actively guiding tourists' consumption preferences towards short-haul tourism and longer stays can the production structure of the tourism industry be gradually transformed towards the optimal scenario, which will be extremely challenging. Nevertheless, the primary purpose of this study is to demonstrate what is the optimal tourism industrial structure in the context of the current level of technology and energy structure, so as to provide a strategic direction for energy conservation and emission reduction in the tourism industry against the background of a low carbon economy. Specifically, according to the optimal values calculated in the present study, we can arrange the responsibility of energy conservation and emission reduction for different types of sectors in a differentiated and targeted manner. In other words, the government should focus its emission reduction efforts on tourism-related sectors in the constrained emission group (e.g. Air Transport (T1); Road Transport (T2); Water Transport (T3); Railway Transport (T4); Management of Water Conservancy, Environment and Public facilities (T9); and Leasing Services (T16)), while moderately relaxing the emission constraints of sectors in the encouraged emission group so that they can develop in their conventional development patterns, thus enabling the whole economy to balance economic growth and emission reduction.

The main limitations of this paper are as follows: first, tourism subsectors are not independent of each other, which means that when one tourism subsector (e.g. transport) is suppressed, it may hinder the development of other tourism subsectors. Although the optimisation model for calculating the optimal share of each tourism-related sector is based on the IO equilibrium relationship between sectors within the national economic system, the shares of the six tourism subsectors (i.e. Transportation, Accommodation, Shopping, Food, Travel, and Other Tourism) are calculated by further processing the optimal values of the 18 tourism-related sectors with the coefficient stripping method, which does not take into account the inter-sectoral dependencies within the tourism system. Therefore, the increase or decrease in the total output of the six tourism subsectors under the optimal scenario presupposes that these subsectors are independent of each other within the tourism system. in other words, a decline in the total output of one tourism subsector under the optimal scenario does not mean that any of the other tourism subsectors will be inhibited as a result. In this sense, it is difficult to achieve the structural state of the tourism industry in the optimal scenario unless there are changes in the input-output structure, travel preferences and tourism consumption structure within the tourism system (Arriaga Navarrete & González ; Sun et al., 2020; Sinha et al., 2019; Tang et al., 2017). Second, this study aims to develop a novel analytical framework by the combined use of the EIO-based linkage analysis and a multi-objective programming model to pioneer low-carbon tourism research, and the application of this proposed analytical framework is simplified in several respects. For example, it is based on a single year's data and thus cannot provide information on the dynamic changes of the optimal tourism industrial structure. In the process of constructing the multi-objective programming model, we consider only the core objective functions and constraints, without considering factors such as job creation, consumer preferences, industrial competitiveness, renewable energy substitution, and technological change; these should be topics for further research. Third, although the optimisation results of this paper present an optimal tourism industrial structure in an ideal scenario that can balance economic growth and emission reduction, we should note that the tourism industrial structure is profoundly influenced by a range of factors such as institutional environment, cultural background, endowment resources, economic development and consumer preferences (Ghosh, 2020; Sun et al., 2020; Tang et al., 2017; Zha et al., 2020). Without considering the subjective and objective conditions within the economic system, it would be difficult to adjust the current tourism-related sectors to match the optimal structure results calculated in this paper. Therefore, the optimisation results are limited to suggesting an optimised tourism industrial structure to policy makers based on the current IO equilibrium relationship and showing the priorities for energy conservation and emission reduction among sectors within the economic system, especially within the tourism system. Finally, the diversity and complexity of the economic systems determine that structural change in industry is just one of many ways to help achieve the target of a low carbon economy, and that structural change alone is far from being enough to complete the transition to a low carbon economy. Although this study aims to explore how to change the industrial structure of tourism in an ideal scenario to promote the development of a low carbon economy, an analytical framework that includes other measures (e.g., energy conservation and emission reduction technology, renewable energy substitution, and low carbon consumption) would make our recommendations more operational in a realistic and complex world. Overcoming these limitations is the focus of our research team's future work.

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Appendix

Appendix A

The composition of China's tourism and the scope definition of tourism-related sectors

Tourism components	Tourism-related sectors (sector number)	Tourism components	Tourism-related sectors (sector number)
Transportation	Air Transport （T1）	Other tourism	Culture, Arts and Recreational Activities （T10）
	Road Transport （T2）		Sports Activities (T11)
	Water Transport (T3)		Entertainment Activities (T12)
	Railway Transport (T4)		Information Transmission, Computer Services and Software Industry （T13）
Accommodation	Accommodation （T5）		Postal Industry （T14）
Shopping	Shopping (T6)		Financial Insurance Services （T15）
Food	Food and Beverage services (T7)		Leasing Services （T16）
Travel	Commercial Services (T8)		Resident Services and Other Services （T17）
	Management of Water Conservancy, Environment and Public facilities (T9)		Public Management and Social Organization (T18)

Appendix B

Classification and codes of economic industries

Code number	Industries	Code number	Industries
F1	Agriculture, Forestry, Animal Husbandry and Fishery	C1	Construction Industry
M1	Mining and Washing of Coal	S1	Other Transport
M2	Extraction of Petroleum and Natural Gas	S2	Real Estate
M3	Mining and Processing of Metal Ores	S3	Research and Experimental Development
M4	Mining and Dressing of Non-metallic Ores and Other Ores	S4	Integrated Technology Services
I1	Food manufacturing	S5	Education
I2	Tobacco manufacturing	S6	Health, Social Security and Social Welfare
I3	Textile manufacturing	T1	Air Transport
I4	Manufacture of Textile, Apparel, Shoes, Hats, Leather, Down and Related Products	T2	Road Transport
I5	Wood Processing and Furniture Manufacturing	T3	Water Transport
I6	Papermaking, Printing, Culture, Education, Sporting Goods Manufacturing	T4	Railway Transport
I7	Petroleum Processing, Coking and Nuclear Fuel Processing	T5	Accommodation
I8	Manufacture of Chemical Raw Materials and Chemical Products	T6	Shopping
I9	Non-metallic Mineral Processing and Manufacturing	T7	Food and Beverage services
I10	Metal Smelting and Rolling Processing Industry	T8	Commercial Services
I11	Manufacture of Metal products	T9	Management of Water Conservancy, Environment and Public facilities
I12	General and Special Equipment Manufacturing	T10	Culture, Arts and Recreational Activities
I13	Transportation Equipment Manufacturing	T11	Sports Activities
I14	Electrical Machinery and Equipment Manufacturing	T12	Entertainment Activities
I15	Communication Equipment, Computer and Other Electronic Equipment Manufacturing	T13	Information Transmission, Computer Services and Software Industry
I16	Measuring Instrumentation, Cultural and Office Machinery Manufacturing	T14	Postal Industry
I17	Crafts and Other Related Product Manufacturing	T15	Financial Insurance Services
I18	Waste and Scrap Processing and Recycling	T16	Leasing Services
E1	Production and Supply of Electricity and Heat Power	T17	Resident Services and Other Services
E2	Production and Supply of Gas	T18	Public Management and Social Organization
E3	Production and Supply of Water		

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