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Invited paper

# Evaluation on development efficiency of low-carbon tourism economy: A case study of Hubei Province, China

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ABSTRACT

Tourism is one of the emissions sources of $CO_2$ and tourism activities can impose pressure on the ecological environment. The study constructed an evaluation framework of the direct and indirect $CO_2$ emissions from tourism industry, and included the $CO_2$ emission factor in the efficiency evaluation framework based on SBM-Undesirable model, on the basis of which, the study assessed the $CO_2$ emissions from the tourism industry, taking the cities of Hubei province in China as case studies, and then measured and analyzed the development efficiency of low-carbon tourism economy in the cities and its dynamic fluctuations in the cities from 2007 to 2013. The results show that the total carbon dioxide emissions from tourism in Hubei soared from 6,340,302 tons in year 2007 to 23,939,851 tons in year 2013, with the transportation being the biggest contributor accounting for 50.35% of the total emissions, followed by the food, accommodation, shopping, other services, entertainment, post & telecommunications. While the direct $CO_2$ emission far exceeds that of the indirect in the transportation, the opposite is true in other secondary sectors. Results of efficiency measurement indicate the overall efficiency of low-carbon tourism economy is on a rather low level and varies significantly among the cities, and there are untapped potentials with internal productive factors in the economic system of urban tourism. From the perspective of dynamic shifts, however, the overall efficiency within the analyzed period was on an upward trend, driven primarily by the technological advancements induced by the scale factor, whereas the purely technological efficiency changes undermined the growth of productivity. Finally, the calculation results of slack variables in inputs and outputs based on the efficiency evaluation framework achieved in this study will provide reference for development efficiency modification of low-carbon tourism economy in inefficient cities.

## 1. Introduction

With profound impacts on people's work and life, climate change has become one of the major challenges facing the humanity, and the issue of carbon dioxide emissions struggles politically, economically and diplomatically among world powers. As the world's largest developing country, China will most naturally be subject to increasing pressure to reduce carbon dioxide emission because of the country's expanding energy demand in order to accelerate urbanization and industrialization process and because of the country's energy structure focused on traditional fossil fuels [55]. It has gradually become a consensus shared by the government and non-government organizations to counter the challenge of climate change and tame carbon dioxide emissions, which will impact the entire economic system, including the tourism industry [1,36,56,57]. The United Nations World Tourism Organization research has concluded the tourism sector discharges 4.9% of all anthropogenic carbon dioxide emissions globally and contributes 14% to the global greenhouse effects (http://www2.unwto.org/). Without effective countermeasures, carbon dioxide emissions by the world tourism sector are projected to grow 2.5% annually on average until year 2035 [54]. Considering year 2013 saw 129 million tourist visits to China, 98 million Chinese tourist visits abroad, and 3.262 billion domestic tourist visits, it is undeniable that tourist activities and associated operations of such a scale would consume considerable energies and produce immense $CO_2$ emissions either directly or indirectly [18]. What implications will the low-carbon restriction have on the development of tourism economy in Chinese cities? Answer to the question carries major significance for the development of tourism economy in China.

It is evident that tourism growth could impose an increasing pressure on climate change, while tourism has extreme sensibility and fragility when facing the climate change [17,40,48,52,58]. Although the negative impact of tourism development and tourist activities on the quality of the environment via climate change has gradually been

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highlighted [46], the relationship between tourism and $CO_2$ emissions was relatively underexplored. However, previous studies focus on the estimation of tourism-related carbon emissions under different spatial scales, mainly measuring the carbon dioxide emissions from tourism transportation [11,24,37], tourism accommodation [10,23,35,43,53], tourism activities [9,20,33] and tourism industry [8,21,29,32,47,51]. It is acknowledged that carbon dioxide emissions from tourism industry have two types, one is direct carbon dioxide emissions referring to the $CO_2$ emissions directly caused by final energy consumption of tourism industry, the other is indirect carbon dioxide emissions referring to the $CO_2$ emissions caused by embodied energy consumed during producing process of intermediate products of tourism-related industries. Some scholars have estimated the direct and indirect carbon dioxide emissions from the tourism industry in Switzerland [45], Australia [21], Romania [16], China [39], and Welsh [28]. In recent years, the measurement on carbon dioxide emissions for tourism has shown a trend moving from the direct measurement of a specific tourism subsector to the direct and indirect measurement of all the tourism subsectors.

Carbon dioxide emissions are used to evaluate the carbon effect of the system on the environment, but it ignores the benefits of carbon costs for society. Analysis of environmental efficiency to some extent can make up for this deficiency and gain more insights into low-carbon tourism development. Gössling et al. [24] first analyzed the interplay of environmental damage and economic gains within the context of tourism by using tourism eco-efficiency. Eco-efficiency herein is a single-factor indicator and is calculated by the ratio of economic turnover to energy use. Later, some scholars put forward to total-factor indicator instead of single-factor indicator to measure the tourism efficiency avoid the biased estimation by including substitution effect among factors. In response to this shortcoming, different methods and tools are available to study tourism efficiency, while the data envelopment analysis (DEA) has been the most commonly used [7,15,34]. This approach has so far been employed for efficiency study in tourism industry [3,13,49,60] as well as tourism-related hospitality [2,4,12,26,44], transport [14,22] and destinations [6,38,49]. In terms of geographical scope of urban level, Cracolici et al. [19] measured economic efficiency of 103 Italian provinces for the year 2001 by using DEA method. Barros et al. [6] assessed and compared the efficiency of French tourism regions using the DEA two-stage procedure. Medina et al. [38] adopted DEA method to measure technical efficiency of 22 tourism regions in Spain and Portugal for the period 2003–2008. Until the environmental and climate change issues become ever more acute, few scholars take the ecological environmental factor into consideration when constructing the analytical framework of tourism efficiency [25,27,40,48]. However, they failed to devote enough attentions to the issue of $CO_2$ emissions, and explore the development efficiency of tourism economy in cities under low-carbon restrictions.

In this consideration, this study contributes to knowledge by inducting the $CO_2$ emissions factor into the efficiency evaluation framework. Based on the accurate evaluation on $CO_2$ emissions in the tourism industry, we give our assessment and analysis of the development efficiency of low-carbon tourism economy in the cities of Hubei province in China. The study will not only help us to further understand the nature and meaning of sustainable growth of the tourism economy and expand the study of low-carbon tourism, but also provide policy-making reference for the development of tourism economy under the low-carbon economic background.

## 2. Research area

Situated in the middle region of China in the mid-southern section of the Yangtze River between north latitudes 29° 05 ′ and 33° 20′ and east longitudes 108° 21 ′ and 116° 07′, Hubei Province claims a total land area of approximately 185,900 square kilometers and a total resident population of some 58.16 million. The province is surrounded by mountains on its east, west and north sides, while its central area is the Jianghan Plain known as the "land of plenty". Thanks to the ample rivers and lakes, Hubei is celebrated as "the province of a thousand lakes". The province is home to rich natural, cultural and social tourism resources. With the prestigious city of Wuhan, the "one river and two mountains" and the two major tourism belts in the east and west, the local tourism resources feature a diverse variety, extensive distribution, high quality and notable differentiations, e.g., Yellow Crane Tower, Three-Gorges Tribe Scenic Spot, Royal Mausoleum of Ming and Qing Dynasties, Ancient Building Complex in the Wudang Mountains, Shennongjia Scenic Area and so on. In spite of the ballooning downward pressure on economic growth and the dwindling tourism demands internationally and domestically, the tourism sector in Hubei has maintained an excellent growth momentum. According to the statistics of the Tourism Bureau of Hubei, year 2014 saw the province receive 472 million tourist visits and reap a total tourism income of 375.286 billion yuan (13.71% of the province's GDP), increasing by 15.4% and 17.07% respectively. The tourism sector has obviously become one of the key pillars of economic growth in Hubei amidst the dipping economic growth and contracting international demands. As such, we have selected 17 key cities in the province as the research subjects, and assessed and analyzed their $CO_2$ emissions from the tourism sector and the development efficiency of low-carbon tourism economy (see Fig. 1).

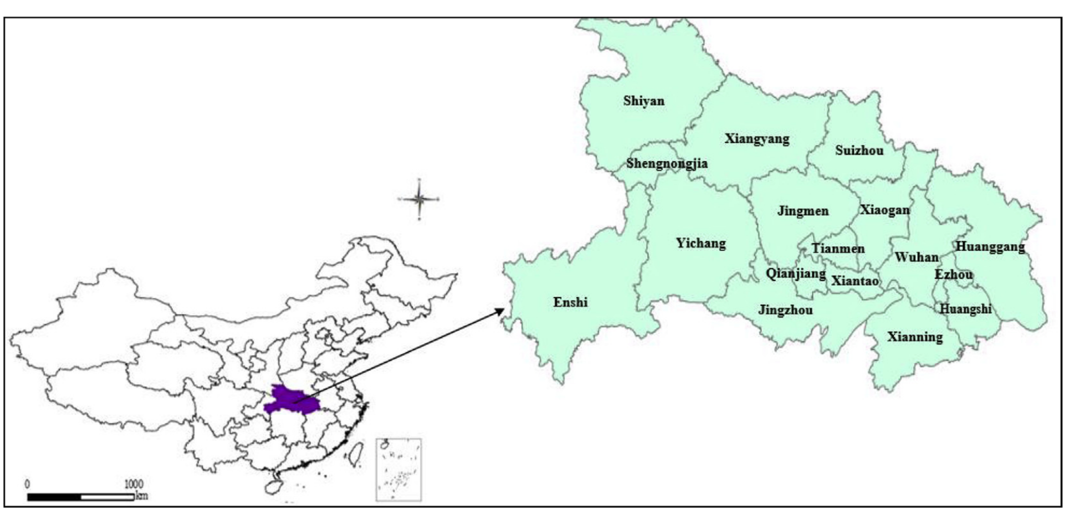


**Fig. 1.** The spatial distribution of 17 cities of Hubei province in China.

## 3. Research methodology

### 3.1. Selection of research method

The existing studies have shown that parametric methods and nonparametric methods are the main methods of efficiency evaluation. Parametric methods contain deterministic parameter method and undeterministic parameter method, with the latter being more frequently used owing to deterministic parameter method lacks definite assumptions of the random error terms in the equation [5,30,31,42]. The nonparametric method is derived from Farrell's research on relative efficiency evaluation, mainly referring to data envelopment analysis (DEA), which is based on the given observed data to find relative effective decision making units. Due to its advantages such as no need to assume a particular functional form, non-subjective weighting and the ability to analyze sources of inefficiency, it has become one of the main methods to evaluate relative efficiency. This paper chooses DEA to evaluate development efficiency of low-carbon tourism economy.

The DEA method mainly encompasses the traditional models like CCR, BCC, FG and ST, but the respective outputs are generally desired outputs that are ignorant of the undesired outputs such as the pressure on the ecological environment produced in the development of tourism economy in cities. Though past researches used a number of methods to deal with the undesired outputs, such as data translation processing method, curve measurement evaluation, directional distance function method and pollution emission & investment treatment method, they neglected the slack issue with inputs and outputs which then undermined the accuracy of the evaluated value of development efficiency. This paper has therefore resorted to the SBM-Undesirable model as the evaluation tool to assess the development efficiency of low-carbon tourism economy in 17 cities of Hubei province, which not only covers the undesired outputs but also shuns the slack issue of inputs and outputs.

### 3.2. Index selection

The rationality in the selection of the input and output indexes determines to a large extent the accuracy of the measurement of DEA efficiency. From the perspective of classic economics, land, labor and capital are the most basic inputs of productive factors in economic activities. It is worth noticing however that the size of land in cities exerts a relatively weaker restriction on the development efficiency of tourism, and therefore natural resources and conditions characterized by land factor may not be regarded as direct inputs in the tourism economy in cities, but the tourism resource endowments closely associated with them play a big role in the growth of tourism, so that tourism resource endowments can be seen as the substitute factors of the land resource. In the principle of scientific soundness, suitability, weak correlation and operability for the selection of input and output targets, we have chosen the tourism resource endowments, labor and capital as the input factors in the tourism sector in cities, represented by the tourism resource endowments (*TRE*), number of employees in the tertiary industry (*ETI*) and urban fixed assets investment (*UFI*) respectively.

In terms of output targets, the tourism sector in all cities attains returns (desired and undesired) by providing services to tourists with different needs, where the external representation of desired return is the total tourism revenue (*TTR*) and the representation of undesired output is the $CO_2$ emission totals (*CET*) from tourism throughout the entire tourism industry chain which indicates the pressure on the ecological environment by the activities of tourism economy against the background of low-carbon economy.

### 3.3. The SBM-Undesirable model

Assume there are 17 cities' tourism industries ($j = 1,2, ...,17$), the $j$ th city's tourism industry consumes $i$ types of inputs $x_{ij}$ ($i = 1,2,3$), respectively is labor, capital, tourism resource endowment, meanwhile produces tourism revenue $y_j$ and $CO_2$ emission $b_j$, then the mathematical expression for the production possibilities set corresponding to the inputs, tourism revenue and $CO_2$ emission of the $j'$th city's tourism sector being evaluated is:

$$P = \left\{(x, y, b): \sum_{j=1}^{n} \lambda_j x_{1j} \le x_{1j'}; \sum_{j=1}^{n} \lambda_j x_{2j} \le x_{2j'}; \sum_{j=1}^{n} \lambda_j x_{3j} \le x_{3j'}; \sum_{j=1}^{n} \lambda_j y_j \ge y_{j'}; \sum_{j=1}^{n} \lambda_j b_j \le b_{j'}; \sum_{j=1}^{n} \lambda_j = 1; \lambda_j \ge 0\right\} \quad (1)$$

Wherein, $P$ is a closed, bounded, convex set of outputs, $\lambda_j$ are the weight variable standing for the weight of the respective observation value of all cities' tourism industries being evaluated, the restrictive term of $\sum_{j=1}^{n} \lambda_j = 1$ would suggest the production technology is variable returns to scale (VRS) or otherwise constant returns to scale (CRS). Based on the production possibilities set, the SBM-Undesirable model that covers the undesired output ($CO_2$ emission) is constructed as follows:

$$\rho* = \min \frac{1 - \frac{1}{3}\sum_{i=1}^{3} \frac{s_{ij'}^{-}}{X_{ij'}}}{1 + \frac{1}{2}\left(\frac{s_{j'}^{d}}{y_{j'}} + \frac{s_{j'}^{u}}{b_{j'}}\right)}$$

$$\begin{aligned} s.\,t.\quad & x_{1j'} = \sum_{j=1}^{n} \lambda_j x_{1j} + s_{1j'}^{-}; \quad x_{2j'} = \sum_{j=1}^{n} \lambda_j x_{2j} + s_{2j'}^{-}; \quad x_{3j'} = \sum_{j=1}^{n} \lambda_j x_{3j} + s_{3j'}^{-};\\ & y_{j'} = \sum_{j=1}^{n} \lambda_j y_j - s_{j'}^{d}; \quad b_{j'} = \sum_{j=1}^{n} \lambda_j b_j + s_{j'}^{u}; \quad 1 = \sum_{j=1}^{n} \lambda_j\\ & \lambda_j \ge 0, \forall j; s_{1j'}^{-} \ge 0; \quad s_{2j'}^{-} \ge 0; s_{3j'}^{-} \ge 0; \quad s_{j'}^{d} \ge 0; s_{j'}^{u} \ge 0. \end{aligned} \quad (2)$$

In which, $s_{1j'}^{-}$, $s_{2j'}^{-}$ and $s_{3j'}^{-}$ represent input redundancies, $s_{rj'}^{d}$, $s_{kj'}^{u}$ respectively represent the shortfall of tourism revenue and superscalar of $CO_2$ emission of the $j'$th city's tourism sector, and the development efficiency $RE=\rho*$ in which $\rho*$ is the target function and is strictly decreasing, and $0 < \rho* \le 1$, meaning the bigger the $\rho*$, the bigger the development efficiency, and vice versa. Through the Charnes-Cooper conversion, we can achieve the dual linear programming model of the foregoing nonlinear programming model, and then find the solution from the SBM-Undesirable model.

### 3.4. Construction and decomposition of TFP index

The SBM-Undesirable model evaluates the static level of development efficiency of low carbon tourism economy in cities [41]. To offer a dynamic analysis, the Luenberger TFP index(Total Factor Productivity) of low-carbon tourism economy in cities is constructed as follows:

$$LTFP_t^{t+1} = CPRE_{CRS}(t+1) - CPRE_{CRS}(t) \quad (3)$$

wherein, $LTFP_t^{t+1}$ is the Luenberger TFP index from period $t$ to period $t+1$, and $CPRE(t+1)$ and $CPRE(t)$ refer to the development efficiency of period $t+1$ and period $t$ within the inter-period *DEA*, that is, constructing the frontiers of production technology with all cities'tourism sectors in the analyzed period as the reference points, so as to measure the development efficiency of the city's tourism economy being evaluated in period $t+1$ and period $t$, with the CRS standing for constant returns to scale. $LTFP_t^{t+1} > 0$ means the development efficiency of low-carbon tourism economy in cities increase, and vice versa. Similarly, we can further decompose the Luenberger TFP index into technological efficiency change ($LEC_t^{t+1}$) and technological advancement ($LTP_t^{t+1}$), that is:

$$LEC_t^{t+1} = CRE_{CRS}(t+1) - CRE_{CRS}(t) \quad (4)$$

$$LTP_t^{t+1} = TG_{CRS}(t+1) - TG_{CRS}(t) \quad (5)$$

In formula (4), $CRE(t+1)$ and $CRE(t)$ represent the development efficiency of period $t+1$ and period $t$ respectively in the current period

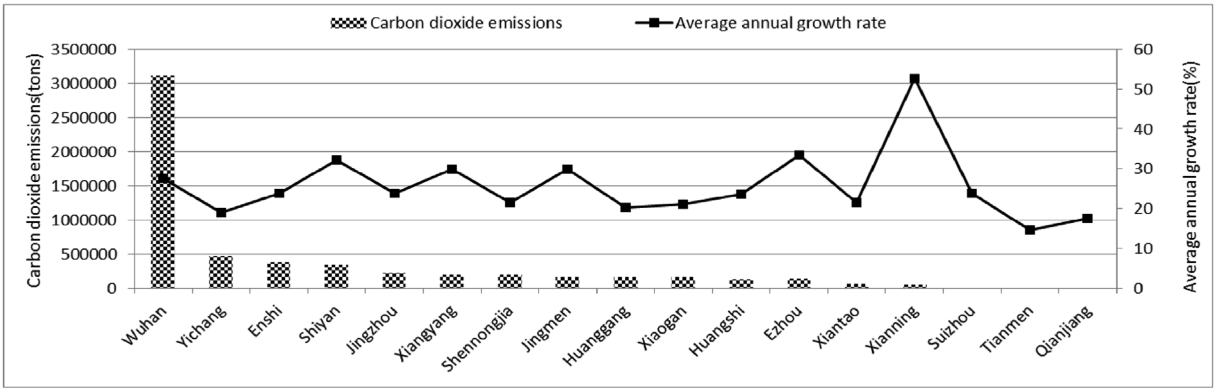


**Fig. 2.** Average Annual Direct $CO_2$ Emissions from the Tourism Sector and Average Annual Growth Rate in Cities.

*DEA*, which means constructing the frontiers of production technology with all samples in period $t+1$ (period $t$) as the reference points to calculate the development efficiency of all cities' tourism industries being evaluated in period $t+1$ (period $t$). $TG(t+1)$ and $TG(t)$ stand for the technological differences between period $t+1$ and period $t$ respectively, that is, the difference of development efficiency of the targets measured under different technological frontiers in inter-period *DEA* and current period *DEA*. $TG(t+1) > TG(t)$ means the technology has advanced, or otherwise, degenerated. After considering the factor of scale efficiency, we can further break the technological efficiency into pure efficiency change (*LPEC*) and scale efficiency change (*LSEC*), thus breaking the technological advancement into pure technological advancement (*LPTP*) and technological scale change (*LTSC*), as follows:

$$LPEC_t^{t+1} = CRE_{VRS}(t+1) - CRE_{VRS}(t) \tag{6}$$

$$LSEC_t^{t+1} = [CRE_{CRS}(t+1) - CRE_{VRS}(t+1)] - [CRE_{CRS}(t) - CRE_{VRS}(t)] \tag{7}$$

$$LPTP_t^{t+1} = TG_{VRS}(t+1) - TG_{VRS}(t) \tag{8}$$

$$LTSC_t^{t+1} = [TG_{CRS}(t+1) - TG_{VRS}(t+1)] - [TG_{CRS}(t) - TG_{VRS}(t)] \tag{9}$$

## 4. Data sources

With regard to the data of input-output indexes, the difference in the number of different levels of tourist sites reflect the difference in tourism resource endowment in cities (refer to Tan [50]). In this study, we use the *Classification and Evaluation of Quality Ratings of Tourist Attractions* (GB/T17775-2003) as the reference for the classification of scenic spots, then 3A, 4A, 5A grade scenic spots were assigned to the score of 3, 4, 5 respectively. The score of tourism resources in each city, representing for tourism resource endowments (*TRE*), were calculated through weighted average method, namely, comprehensive score of tourism resources of each city is obtained through the weighted mean of the scores of scenic spots. The number of employees in the tertiary industry (*ETI*) and the data of fixed asset investments in cities (*UFI*) come from the *Statistical Yearbook of Hubei Province(2008–2014)*. Meanwhile, the total revenue from tourism industry (*TTR*) is found in the *Factsheet of Tourism in Hubei* and the indexes of monetary value in this study like fixed asset investments in cities and total tourism revenue (*TTR*) are calculated with the constant prices of 2007, and the fixed-asset investment price index and consumer price index come from the *Statistical Yearbook of Hubei Province (2008–2014)*.

As for the undesired output index, the $CO_2$ emissions from the tourism industry (*CET*) are calculated according to the evaluation method (refer to Appendix A) and the input-output tables used in the calculation of $CO_2$ emissions between 2007 and 2011 from the tourism sector in this research are from the *World Input-Output Database*. Besides, the *2011 Chinese input–output table* is updated to 2013, using a modified Stone's RAS method (refer to Zeineldin [59]), and the corresponding direct consumption coefficient matrices and Leontief inverse matrices can be obtained through further calculation according to the above evaluation method. The spending and proportions of foreign visitors and domestic tourists are excerpted from the *Factsheet of Tourism in Hubei* provided by the provincial tourism authority of Hubei, where the tourism spending comprises mainly of transport, accommodation, food, shopping, entertainment, post & telecommunications and other services, and the data of intermediary and terminal energy consumption and its structure are from the *Chinese Energy Statistical Yearbook(2008–2014)*.

## 5. Results and discussion

### 5.1. $CO_2$ emissions from tourism in cities

For direct $CO_2$ emissions from tourism sector, Fig. 2 shows the average annual amounts and annual growths of direct $CO_2$ emissions from the tourism sector in 17 cities in Hubei from 2007 to 2013. According to the figure, the city of Wuhan tops the list in terms of average annual direct CO2 emissions at 3,118,073 tons, followed by Yichang (473,381tons), Enshi (388,130 tons), Shiyan (356,751tons), Jingzhou (227,199 tons) and bottomed out by Qianjiang (9269 tons). The differences between the cities are stark, with the highest being 336 times of the lowest. The direct $CO_2$ emissions soared between 2007 and 2013 at an average annual growth rate of between 14.49% and 52.62%.

In the composition of direct $CO_2$ emissions from the tourism industry, the differences in secondary segments like transport, accommodation, food, shopping, entertainment, post & telecommunications and other services are insignificant among the cities, with the transport segment contributing the most at 79.11% of the annual total, followed by accommodation (7.95%), shopping (4.22%), food (3.75%), other services (3.02%), entertainment (1.70%), and post & telecommunications (0.25%). Owing to the small changes in primary energy consumption structure and carbon emission coefficient of various types of energy during the analysis period, the direct $CO_2$ emissions and the contributing factors of structural changes in regional tourism industry are similar to those of direct energy consumption, they are more affected by the intensity of direct energy consumption and output scale, reflecting the three dimensional changes of energy saving and emission reduction technology, products & services structure and industrial scale. Besides, the proportion of direct $CO_2$ emissions from food, entertainment and post & telecommunications shrank between 2007 and 2013, that of the transport, shopping and other services escalated, and that of the accommodation segment was comparatively stable (refer to Fig. 3).

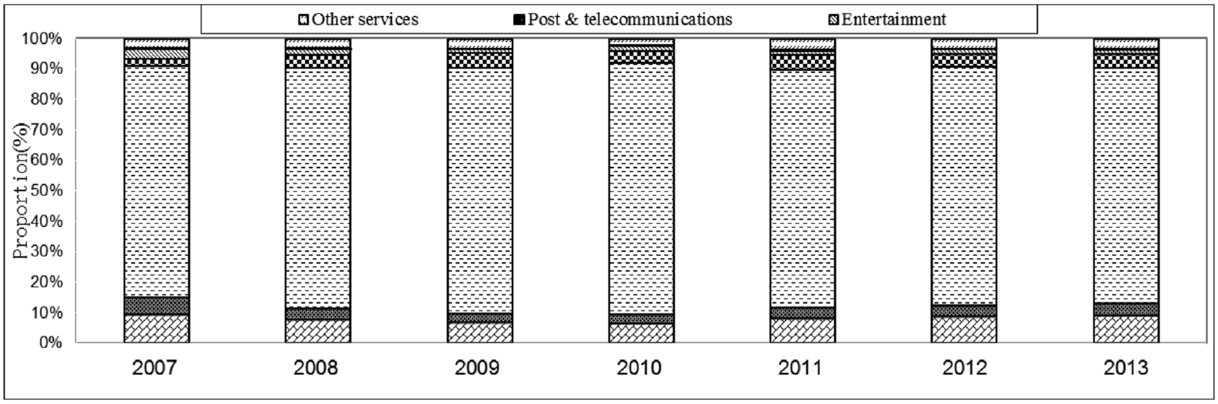


**Fig. 3.** Average Proportions of Direct $CO_2$ Emissions from Secondary Segments of the Tourism Sector, 2007–2013.

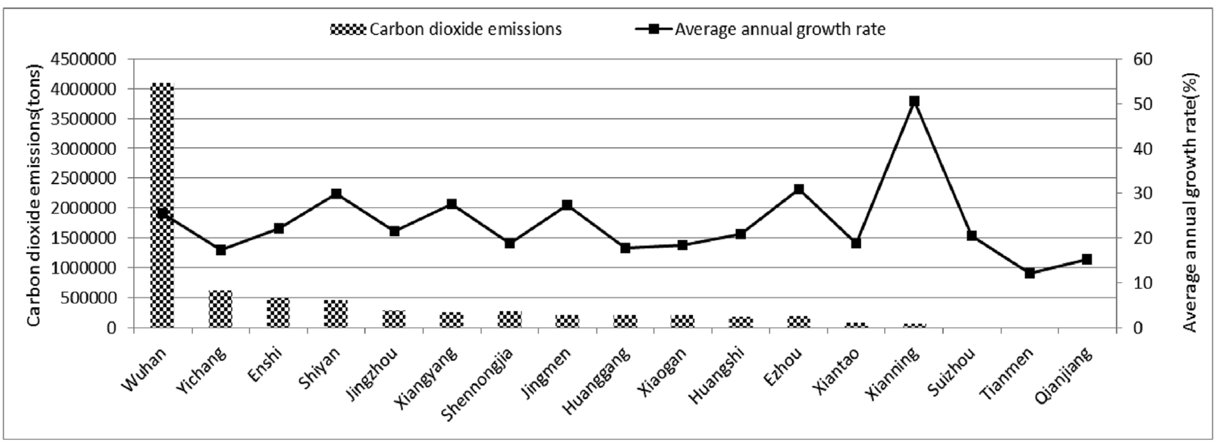


**Fig. 4.** Indirect $CO_2$ Emissions from Tourism Sector in Cities, Hubei Province and Their Average Annual Growth Rates.

In indirect $CO_2$ emissions from the tourism sector, the city of Wuhan also contributed the most at 4,102,509 tons ton average annually, followed by Yichang (629,133 tons), Enshi (502,594 tons), Shiyan (473,096 tons), Jingzhou (305,269 tons) and bottomed out by Qianjiang (12,402 tons), with the highest contributor 331 times of the lowest contributor. The differences between the cities are notable. Indirect $CO_2$ emissions from the tourism sector grew significantly between 2007 and 2013 with an average annual growth rate of more than 12%. Xianning and Ezhou even reported an average annual growth rate of more than 30% (refer to Fig. 4).

With regard to the composition of indirect $CO_2$ emissions from tourism, the proportions of $CO_2$ emissions from the secondary segments of the tourism sector vary slightly from city to city, with the transport segment contributing the most, at an annual average of 28.97%, followed by food (23.52%), accommodation (19.80%), shopping (16.49%), other services (7.74%), entertainment (2.70%) and post & telecommunications (0.79%). Due to the small changes in the energy consumption structure and carbon emission coefficient of various types of energy between 2007 and 2011, the causes of corresponding indirect $CO_2$ emissions and their structural changes are similar to those of indirect energy consumption, they are mainly driven by the indirect energy consumption intensity and output scale. From the dynamic point of view, the proportions of indirect $CO_2$ contributions shrank in the food, entertainment, accommodation and post & telecommunications segments between 2007 and 2013, whereas those in the transport, shopping and other services segments climbed (refer to Fig. 5).

The total $CO_2$ emissions from the tourism sector are comprised of direct and indirect emissions. The total emissions from the tourism sector in cities of Hubei province rose from 6,340,302 tons in 2007 to 23,939,851 tons in 2013. The transport segment led the pack with a 50.35% annual average contribution, followed by food (15.13%), accommodation (14.75%), shopping (11.21%), other services (5.72%), entertainment (2.27%), and post & telecommunications (0.56%). Fig. 6 shows the average annual total of $CO_2$ emissions from the tourism sector and average annual tourism incomes in the cities, where we can see a strong link between the two, suggesting that $CO_2$ emission is an inevitable byproduct of tourism development. The evaluation on development efficiency of tourism economy under low-carbon restrictions therefore carries enormous significance for the development of tourism in cities against the low-carbon background today.

### *5.2. Development efficiency of low-carbon tourism economy in cities*

Based on the SBM-Undesirable model, we evaluated the development efficiency of low-carbon tourism economy in 17 cities of Hubei province between 2007 and 2013 using the Matlab analytical software. The results show the average values of the development efficiency at 0.847, 0.867, 0.858, 0.797, 0.754, 0.741 and 0.736 respectively in the 7 years, while the overall value rests at a low 0.8, which means the outputs could increase 20% if the potentials of the internal productive factors in the tourism economic system of the cities were fully unleashed in the period.

Fig. 7 indicates the average annual values of the development efficiency of low-carbon tourism economy in Hubei cities between 2007 and 2013 from the geographical point of view. According to Fig. 7, cities like Wuhan, Shennongjia, Xiantao, Tianmen and Qianjiang led the technological frontier in the sampled period with average annual efficiency value at 1.000, and were followed by Enshi (0.946), Shiyan (0.943), Jingmen (0.932), Ezhou (0.922), Huanggang (0.873), Jingzhou (0.812), Yichang (0.744), Xiaogan (0.673), Huangshi (0.621), Suizhou

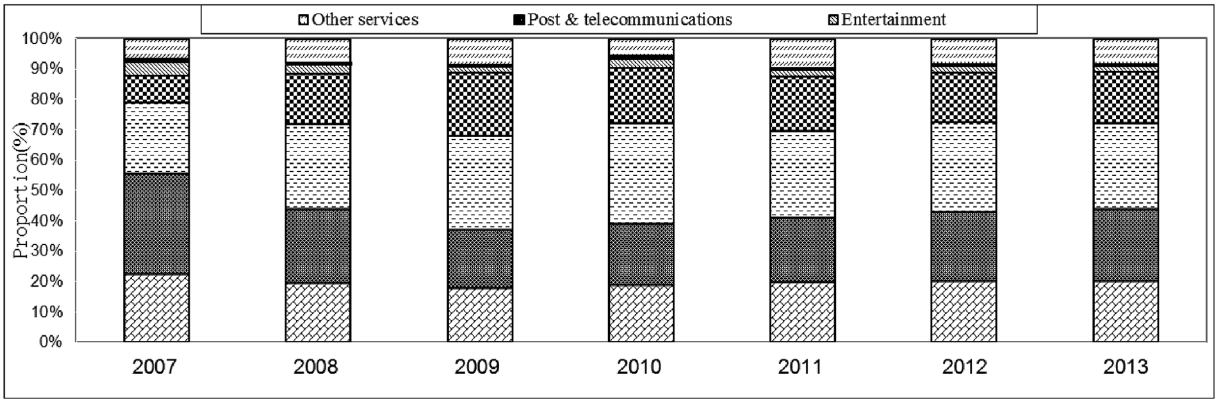


**Fig. 5.** Proportions of Indirect $CO_2$ Emissions from Secondary Segments of Tourism Sector, 2007–2013.

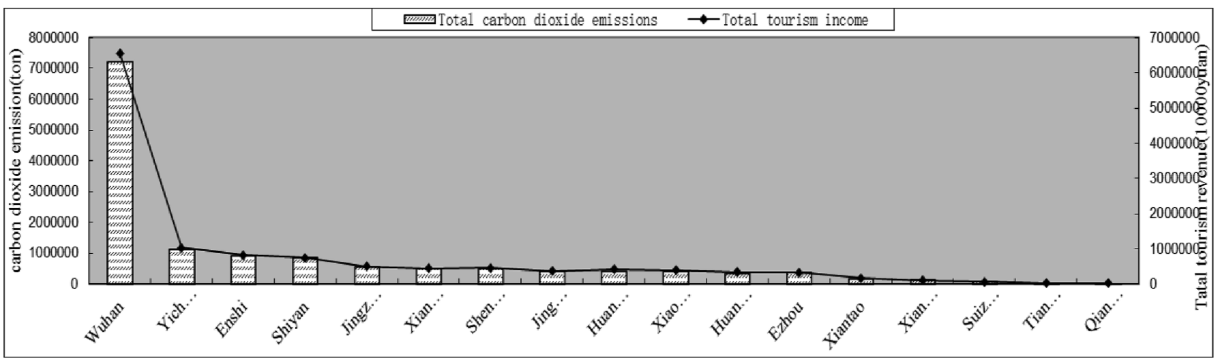


**Fig. 6.** Average Annual $CO_2$ Emission Totals and Incomes from Tourism Sector in Cities.

(0.548), Xiangyang (0.516), Xianning (0.322). The highest value is 3.1 times the lowest value, suggesting a notable difference of the development efficiency among the cities. As a national comprehensive reform pilot area for resource-saving and environment-friendly social construction in China, the average development efficiency of low-carbon tourism economy of 9 cities in Wuhan Metropolitan Area is about 0.348, while the average development efficiency of low-carbon tourism economy of 8 cities in Eco-Cultural Tourism Circle of Western Hubei reached 0.505. From the perspective of dynamic change, the development efficiency of low-carbon tourism economy in Wuhan, Shiyan, Jingzhou, Xiangyang, Jingmen, Huangshi, Ezhou, Xiantao, Tianmen, Qianjiang and other cities did not decline under the double dimensions of economic development and ecological environment protection but it showed an upward trend instead, illustrating that these cities tend to be more resource intensive and environmentally friendly. In addition, the development efficiency of low-carbon tourism economy in Yichang, Enshi, Huanggang, Xiaogan and other cities as a whole showed a decline, corresponding to its tourism economy which tend to waste resources and pollute the environment while the development efficiency of low-carbon tourism economy in Shennongjia, Suizhou and other cities is relatively stable on the whole.

### *5.3. Dynamic changes of development efficiency of low-carbon tourism economy in cities and their decomposition*

Luenberger TFP evaluation of low-carbon tourism economy in cities indicates the average Luenberger TFP value of cities in Hubei province was at 0.052 between 2007 and 2013, and the average value of development efficiency rose from 0.379 in 2007 to 0.647 in 2013, registering a notable rise of relative efficiency. All cities except Enshi, Xiaogan, Yichang and Huanggang reported an average productivity value above zero, meaning the development efficiency in most of the

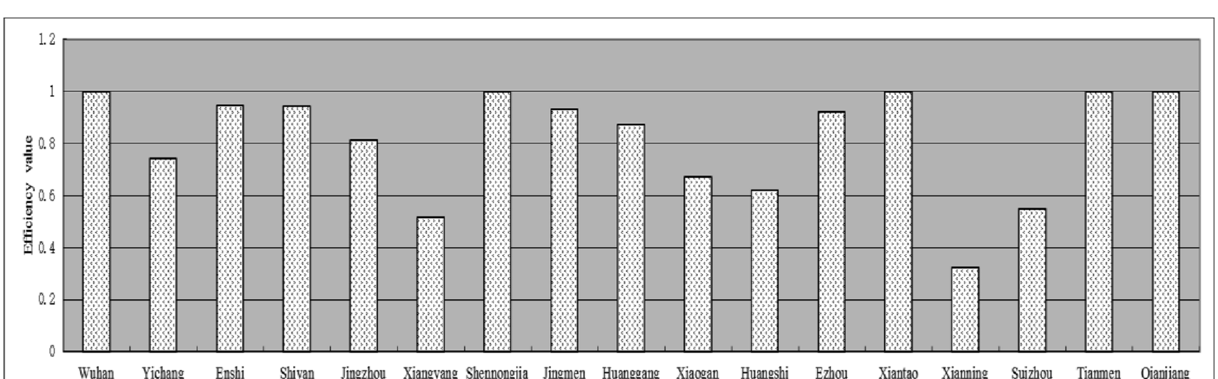


**Fig. 7.** Average Annual Values of Low-Carbon Tourism Economy Development Efficiency in Cities.

cities was going up, especially in Ezhou, Jingmen, Xiantao and Wuhan whose average productivity value was over 0.1. The trajectory of changes shows the average Luenberger TFP value at 0.016, 0.023, −0.077, 0.236, 0.214, 0.112 in years 2008, 2009, 2010, 2011, 2012 and 2013. The development efficiency therefore was increasing in all the years except 2010. The decomposition results of the Luenberger TFP of low-carbon tourism economy show the average value of LPEC, LSEC, LPTP and LTSC at −0.031, 0.008, 0.032 and 0.043 and their contributions to the productivity at −59.62%, 15.39%, 61.54% and 82.69% respectively. Technological advancement (pure technological advancement and change of technological scale) is thus one key factor propelling the rise of development efficiency of low-carbon tourism economy in cities, among which the frontier advancement of production technology induced by scale factor is the primary motive, while the change of technological efficiency (change of pure technological efficiency and scale efficiency) has relatively small influence, with pure efficiency changes even exerting negative impact on the growth of productivity.

When it comes to specific cities, Enshi, Xiaogan, Yichang and Huanggang saw their average value of productivity negative, with the decline of tourism economic development efficiency primarily caused by the degradation of pure technological efficiency, while that of other cities was positive, with the rise of development efficiency in Jingzhou Xiangyang, Jingmen, Ezhou, Xiantao, Tianmen and Qianjiang caused mainly by the change of technological scale in technological advancement, Wuhan, Shiyan and Huangshi mainly by pure technological advancement, and Shennongjia, Xianning and Suizhou mostly by the change of scale efficiency in technological efficiency changes (refer to Fig. 8). Therefore, we should pay particular attention to the absorption and diffusion of technical innovation when intensifying the introduction of tourism-related technologies and independent innovation for inefficient cities, like enhancing the agglomeration of low-carbon tourism development and taking the road of large-scale development, then fully explore the potential for efficiency improvement, finally narrow the gap with advanced cities.

### 5.4. Improving development efficiency of low-carbon tourism economy in cities

The current SBM-Undesirable model builds the frontier of production technology using all current samples as the reference points, so the size of corresponding slack variables reflects the approaches to improve the development inefficiency of low-carbon tourism economy in cities. To save the space, this research only shows the improvement potentials of inputs and outputs in inefficient cities in 2013. Table 1 reports certain differences exist between the increase and decrease proportions of the same slack variable in different inefficient cities whose low-carbon tourism development efficiency are less than 1. This may be due to differences in resource endowment, industrial structure and developmental stage, hence different policies should by formulated by government combining with local characteristics for improving development efficiency of low-carbon tourism. Through Table 1, the direction of policies formulation can be put into four categories, namely TRE, ETI, UFI and CET. In terms of TRE, the redundancy in Xianning is highest (92%), followed by Yichang (80%), Xiangyang (59%), Suizhou (57%), Xiaogan (56%) and Huanggang (54%), indicating that the ability of tourism resource allocation is weak among these cities. They should deeply explore development potential of local tourism resources, optimize and enrich tourism products portfolio to refrain from wasting plenty tourism resources. Besides, Xianning also has a high redundancy of labor input (ETI) and capital investment (UFI) with the proportion of 66% and 68%. In this context, the scale and structure of inputs in Xianning is not reasonable and the potentials of the existing inputs are not fully exploited. Yichang, Xiangyang, Huanggang, Xiaogan, Huangshi and Suizhou have inputs' redundancy similar to Xianning. To boost their development efficiency of low-carbon tourism economy, they need to deeply explore the potential of input factor utilization, shift from the pursuit of intake of inputs to the cultivation of quality, meanwhile, establish a communication platform for tourism information exchanges between cities to accelerate the flow of factors as well as maximize the transformation of inputs into market benefits leading to higher utilization efficiency of inputs. Meanwhile, compared with inefficient cities, frontier cities can also push their production technology frontier forward through pure technological advancement and changes of technological scale, thus further achieving low-carbon tourism.

**Table 1**
Increase & Decrease Proportions of Input and Output Targets in Inefficient Cities, 2013.

| City | TRE | ETI | UFI | TTR | CET |
|---|---|---|---|---|---|
| Yichang | 80% | 49% | 43% | 0% | 0% |
| Enshi | 32% | 0% | 5% | 0% | 1% |
| Xiangyang | 59% | 55% | 50% | 0% | 0% |
| Huanggang | 54% | 66% | 54% | 0% | 0% |
| Xiaogan | 56% | 75% | 53% | 0% | 0% |
| Huangshi | 36% | 42% | 46% | 0% | 0% |
| Xianning | 92% | 66% | 68% | 0% | 0% |
| Suizhou | 57% | 58% | 54% | 0% | 2% |

In the process of improving development efficiency of low-carbon tourism economy, it is paramount to strengthen public capital investment and policy support as a guarantee. Low-carbon tourism services are high-tech and high-capital products, and their positive externalities are obvious, which means that the investment of unit product of tourism firms cannot be completely compensated for in the total sales revenue of their unit product resulting in tourism firms lack activity in low-carbon tourism development. Generally, the production of low-carbon development in Hubei Province is still at initial stage as a whole, government need further increase public capital investment in the

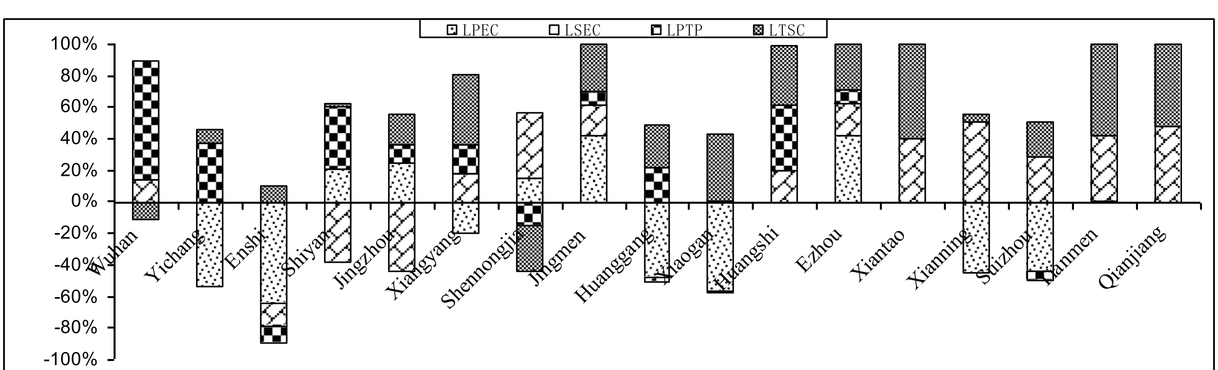


**Fig. 8.** Contributions of Luenberger TFP Items in Low-Carbon Tourism Economy in Cities, Hubei.

production and operation of low-carbon tourism services as well as implement preferential treatment involving finance, tax, credit, land approval to provide policy guarantee for improving the efficiency of providing low-carbon tourism services.

## 6. Conclusions

In the research, we built an evaluation framework of the direct and indirect $CO_2$ emissions from tourism sector, taking Hubei province of China as a case study, and included the $CO_2$ emission factor in the efficiency evaluation framework, on the basis of which, we evaluated the development efficiency of low-carbon tourism economy and analyzed its dynamic changes. The main conclusions reached in this research are as follows:

(1) In the 2007–2013 period, the city of Wuhan emitted the largest amount of $CO_2$ on annual average which amounts to 7,220,582 tons, while Qianjiang contributed the least at 21,671 tons, creating a 333 times difference between the two. The total amounts of $CO_2$ emissions expanded rapidly in these cities, at an average annual growth rate of over 10%. Among the secondary sectors, the accommodation, food, shopping, entertainment, posts & telecommunications and other services segments contributed much more indirect $CO_2$ emissions than direct emissions, while the transport division produced less indirect than direct emissions. Moreover, the transport division contributed the highest proportion of the $CO_2$ emissions, followed by food, accommodation, shopping, other services, entertainment and post & telecommunications, among which the contribution of food, entertainment, accommodation and post & telecommunications segments declined, whereas the emissions from transport, shopping and other services segments escalated.

(2) The development efficiency of low-carbon tourism economy in the 17 cities of Hubei province is at a rather low level, where notable differences exist among the cities and the potentials of the internal production factors of the tourism economic system are yet to be tapped. The results of the Luenberger TFP evaluation show technological advancement is the key factor propelling the rise of development efficiency of low-carbon tourism economy in cities, among which the frontier advancement of production technology induced by scale factor is the primary motive, while the change of technological efficiency has relatively small influence, with pure efficiency changes even exerting negative impact on the growth of productivity. The technological efficiency and technological advancement exert different forces on the Luenberger TFP in the tourism sector of different cities, thereby resulting in the differences in the changing trends of development efficiency of low-carbon tourism economy in different cities.

(3) Calculation of slack variables of inputs and outputs based on the current SBM-Undesirable model shows the situations of input redundancy, insufficient desired outputs and excessive undesired outputs, provides guidance for inefficient cities to improve their development efficiency, wherein inefficient cities can refer to the frontier cities as the benchmark to shrink the input and output slack variables through improvement of technological efficiency, while cities at the frontier production technology can boost their development efficiency of low-carbon tourism economy through technological advancement.

Due to the difficulty in data access, this research is mainly confined by the selection of proxy indicators of inputs and outputs. In spite of the data restriction, the analytical approach as a tool for $CO_2$ emissions and efficiency evaluation provides a foundation for the research on development efficiency of low-carbon tourism economy in the cities.

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## Appendix A. Evaluation on $CO_2$ Emissions from the Tourism Industry

Mainly two approaches, “from top to the bottom” and “from bottom to the top”, were employed in the measurement of $CO_2$ emissions from the tourism industry in past research. Refer to Becken et al. [10] for their respective applicable conditions and advantages and disadvantages. The total amount of $CO_2$ emissions from the tourism industry is closely linked with the energies consumed by the sector, mainly including direct and indirect energy consumption and $CO_2$ emissions. The direct energy consumption by the tourism industry can be computed as:

$$TE^{direct} = \sum_{j=1}^{n} T_j \times ei_j^{direct} \tag{A1}$$

wherein, $j$ ($j = 1,2, \ldots, n$) refers to the specific tourism segments such as accommodation, food, transport, shopping, entertainment, post & telecommunications and other services; $TE^{direct}$ is the physical quantity of energies directly consumed by the tourism sector; $T_j$ is the total revenue from segment $j$ of the tourism sector; and $ei_j^{direct}$ is the direct energy consumption intensity of segment $j$. We can calculate the direct energy consumption intensity of sector $j$ as the ratio of the total energy consumption of sector $j$ in physical units to the total output of sector $j$ in monetary units, and the total energy consumption of sector $j$ in physical units is calculated as the ratio of the total energy being consumed by sector $j$ in monetary units to the corresponding energy prices. To achieve energy prices, we assume $h_1$ (row) and $h_2$ (column) as subscripts to denote energy sectors. With data extracted from the Input-Output Tables and Energy Balance Sheets, we can calculate the weighted-average price of energy sector $h_1$, as the ratio of the summation of all intermediate inputs of energy sector $h_1$ in monetary units to the total consumption of intermediate energy $h_1$ in physical units. Based on Input-Output Tables and Energy Balance Sheets, weighted-average energy price formula is as follows:

$$P_{h_1}^{E} = \frac{X_{h_1} - Y_{h_1}^{ex} + Y_{h_1}^{im} - Y_{h_1}^{final} - \sum_{h_1=1}^{c} X_{h_1h_2}}{E_{h_1}^{S} - E_{h_1}^{Y} - \sum_{h_2=1}^{c} E_{h_1h_2}} \tag{A2}$$

wherein, $P_{h_1}^{E}$ is the weighted-average price of energy products of sector $h_1$, and the corresponding energy products mainly include primary energy , such as coal products, crude oil, natural gas, hydro-electricity, wind electricity and nuclear electricity, and secondary energy such as coke, refined petroleum, fuel burning electricity and heat.[1] $X_{h_1}$, $Y_{h_1}^{ex}$, $Y_{h_1}^{im}$, $Y_{h_1}^{final}$ respectively represent monetary value of energy production, monetary value of

[1] As more than one energy sectors are in consolidation state in Input-Output Tables, the paper takes the consolidation of multi-energies as an integrated energy instead of a single type of energy to calculate the comprehensive price of multi-energies, for instance, the comprehensive price of coal products and crude oil, the comprehensive price of electricity, heat and natural gas. On the basis, the total energy consumption of each sectors could be calculated.

energy export, monetary value of energy import, monetary value of final energy consumption in Input-Output Table. $c$ is the total number of all-type energy industry. $X_{h_1h_2}$ is the monetary value of energy $h_1$ consumed as raw material inputs in monetary units during production process of energy industry $h_2$. $E_{h_1}^{S}$ and $E_{h_1}^{Y}$ respectively represent total energy consumption of energy $h_1$ in physical units and final energy consumption of energy $h_1$ in physical units. $E_{h_1h_2}$ is the physical quantity of energy $h_1$ consumed as raw material inputs during production process of energy industry $h_2$ in Energy Balance Sheet, refraining from repetitive computation of primary energy in secondary energy's calculation. On this basis, direct energy consumption intensity ($ei^{direct}$) formula of tourism-related specific industry is as follows:

$$ei_j^{direct} = \frac{\sum_{h_1=1}^{c} \frac{X_{h_1j}}{P_{h_1}^{E}}}{X_j} \tag{A3}$$

wherein, $j$ is the specific industry type that corresponds to the above-mentioned secondary sector of tourism industry in Input-Output Table. $X_{h_1j}$ is the monetary value of energy $h_1$ of sector $j$'s consumption in Input-Output Table. Moreover, the monetary value of energy $h_1$ of energy industries' consumption refers to the difference between energy input and output in Input-Output Table, which is the loss during the process of energy conversion, and it is calculated by multiplying the monetary value of energy type $h_1$'s input for energy industries in Input-Output Table with the ratio of processing conversion loss to the total energy input in Energy Balance Sheet. $X_j$ is monetary value of industry $j$'s total output. According to the IPCC carbon emissions accounting method, the direct $CO_2$ emissions from the tourism sector is calculated as follows:

$$C^{direct} = \sum_{h=1}^{H} TE^{direct} \times \eta_h \times CE_h \times O_h \times \frac{44}{12} \tag{A4}$$

wherein, $C^{direct}$ is the direct $CO_2$ emissions from the tourism sector, $h$ ($h = 1,2, \ldots, H$) is the types of energies consumed, $\eta_h$ is the initial energy consumption structure in China, $CE_h$ is the carbon emission coefficient of energy $h$, and $O_h$ is the oxidation coefficient of energy $h$(refer to IPCC report 2007). Total energy consumption intensity refers to the total amount of energies consumed to produce the final unit of product or service, and is computed by multiplying the direct energy intensity row vector with the Leontief inverse matrix, that is:

$$EI^{total} = EI^{direct} \times (I - A)^{-1} \tag{A5}$$

wherein, $EI^{total}$ and $EI^{direct}$ stand for the row vector of total energy consumption intensity and that of direct energy consumption intensity which correspond to the vector factors $ei_i^{total}$ and $ei_i^{direct}$ standing for intensity of total energy consumption and direct energy consumption in each segment respectively, A is the direct consumption coefficient matrix, and $(I - A)^{-1}$ is the Leontief inverse matrix. The indirect energy consumption intensity refers to the difference between the total energy consumption intensity and indirect energy consumption intensity. With this data and the carbon emissions accounting method in IPCC report, the paper can achieve the indirect energy consumption ($TE^{indirect}$) by and total $CO_2$ emissions ($C^{indirect}$) from the tourism industry as follows:

$$TE^{indirect} = \sum_{j=1}^{n} T_j \times ei_j^{indirect} \tag{A6}$$

$$C^{indirect} = \sum_{h=1}^{H} TE^{indirect} \times \eta_h \times CE_h \times O_h \times \frac{44}{12} \tag{A7}$$

Hereby, the study can further achieve the total energy consumption ($TE^{total}$) by and total $CO_2$ emissions ($C^{total}$) from the tourism sector through below formulas:

$$TE^{total} = TE^{direct} + TE^{indirect} \tag{A8}$$

$$C^{total} = C^{direct} + C^{indirect} \tag{A9}$$

Table 2
Average calorific values and carbon emission coefficient of different energy types.

| Energy types | Average calorific values per unit | Carbon Emission coefficients | Energy types | Average calorific values per unit | Carbon Emission coefficients |
|---|---|---|---|---|---|
| Coal | 20.908 MJ/kg | 0.0268 kg-c/MJ | Diesel | 42.652 MJ/kg | 0.0202 kg-c/MJ |
| Coke | 28.435 MJ/kg | 0.0258 kg-c/MJ | Fuel oil | 41.816 MJ/kg | 0.0211 kg-c/MJ |
| Crude oil | 41.816 MJ/kg | 0.0200 kg-c/MJ | LPG | 50.179 MJ/kg | 0.0172 kg-c/MJ |
| Petrol | 43.070 MJ/kg | 0.0191 kg-c/MJ | LNG | 38.931 MJ/$m^3$ | 0.0175 kg-c/MJ |
| Kerosene | 43.070 MJ/kg | 0.0196 kg-c/MJ | Refinery gas | 46.055 MJ/kg | 0.0157 kg-c/MJ |

Note: Calorific values and carbon emission coefficient of different energy types are obtained from the Chinese General Principles for Calculation of the Comprehensive Energy Consumption (GB/T2589-2008) and the Chinese Energy Statistics Yearbook (2008).

Table 3
Average calorific values and carbon emission coefficients of electric energy and heat energy.

| Energy types | Average calorific values per unit | | Carbon Emission coefficients | |
|---|---|---|---|---|
| – | – | 2002 | 2007 | 2012 |
| Electricity | 3.596 MJ/kW·h | 0.0624 kg-c/MJ | 0.0594 kg-c/MJ | 0.0510 kg-c/MJ |
| Heat | – | 0.0324 kg-c/MJ | 0.0328 kg-c/MJ | 0.0335 kg-c/MJ |

Note: Calorific values and carbon emission coefficient of electric energy and heat energy are obtained from the Chinese General Principles for Calculation of the Comprehensive Energy Consumption (GB/T2589-2008).

## Appendix B. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.seps.2018.07.003.

## References

[1] Amelung B, Nicholls S. Implications of climate change for tourism in Australia. Tourism Manag 2014;41(41):228–44.
[2] Aminian A. Environmental performance measurement of tourism accommodations in the pilgrimage urban areas: the case of the holy city of Mashhad, Iran. Proc Soc Behav Sci 2012;35:514–22.
[3] Assaf A-G. Benchmarking the Asia Pacific tourism industry: a Bayesian combination of DEA and stochastic frontier. Tourism Manag 2012;33(5):1122–7.
[4] Assaf A-G, Barros C-P, Josiassen A. Hotel efficiency: a bootstrapped metafrontier approach. Int J Hospit Manag 2012;31(2):621–9.
[5] Banker DR, Morey CR. The use of categorical variables in data envelopment analysis. Manag Sci 1986;32(12):1613–27.
[6] Barrio M, Herreio L-C, Sanz J. Measuring the efficiency of heritage institutions: a case study of a regional system of museums in Spain. J Cult Herit 2009;10(2):258–68.
[7] Barros C-P, Botti L, Peypoch N, Robinot E, Solonandrasana B, Assaf G. Performance of French destinations: tourism attraction perspectives. Tourism Manag 2011;32(1):141–6.
[8] Becken S, Patterson M. Measuring national carbon dioxide emissions from tourism as a key step towards achieving sustainable tourism. J Sustain Tourism 2006;14(4):323–38.
[9] Becken S, Simmons DG. Understanding energy consumption patterns of tourist attractions and activities in New Zealand. Tourism Manag 2002;23(4):343–54.
[10] Becken S, Frampton C, Simmons D. Energy consumption patterns in the accommodation sector-the New Zealand case. Ecol Econ 2001;39(3):371–86.
[11] Becken S, Simmons DG, Frampton C. Energy use associated with different travel choices. Tourism Manag 2003;24(3):267–77.
[12] Bernini C, Guizzardi A. Internal and locational factors affecting hotel industry efficiency: evidence from Italian business corporations. Tourism Econ 2010;16(4):883–913.
[13] Brida G-J, Garrido N, Deidda M, Pulina M. Exploring the dynamics of the efficiency in the Italian hospitality sector: a regional case study. Expert Syst Appl 2012;39(10):9064–71.
[14] Brida J-G, Deidda M, Pulina M. Tourism and transport systems in mountain environments: analysis of the economic efficiency of cableways in South Tyrol. J Transport Geogr 2014;36:1–11.
[15] Brida J-G, Deidda M, Pulina M. Investigating economic efficiency in Italy: a regional comparison. Soc Sci Electron Publi 2011;6(3):175–98.
[16] Camelia S, Razvan SM, Breda Z, Ana-Irina D. An input-output approach of $CO_2$ emissions in tourism sector in post-communist Romania. Proc Econ Finance 2012;3:987–92.
[17] Cao Y, Wang BX, Zhang J, Wang LZ, Pan YD, Wang QX, et al. Lake macro-invertebrate assemblages and relationship with natural environment and tourism stress in Jiuzhaigou natural reserve, China. Ecol Indicat 2016;62(6):182–90.
[18] Castellani V, Sala S. Sustainable performance index for tourism policy development. Tourism Manag 2010;31(6):871–80.
[19] Cracolici M, Nijkamp P, Rietveld P. Assessment of tourism competitiveness by analysing destination efficiency. Tourism Econ 2008;14(2):325–42.
[20] Dawson J, Stewart EJ, Lemelin H, Scott D. The carbon cost of polar bear viewing tourism in Churchill, Canada. J Sustain Tourism 2010;18(3):319–36.
[21] Dwyer L, Forsyth P, Spurr R, Hoque S. Estimating the carbon footprint of Australian tourism. J Sustain Tourism 2010;18(3):355–76.
[22] Fernandes E, Pacheco R-R. Efficient use of airport capacity. Transport Res Part A 2002;36(3):225–38.
[23] Filimonau V, Dickinson J, Robbins D, Huijbregts MAJ. Reviewing the carbon footprint analysis of hotels: life Cycle Energy Analysis (LCEA) as a holistic method for carbon impact appraisal of tourist accommodation. J Clean Prod 2011;19(17):1917–30.
[24] Gössling S, Peeters P, Ceron JP, Dubois G, Patterson T, Richardson RB. The eco-efficiency of tourism. Ecol Econ 2005;54(4):417–34.
[25] Horng J-S, Hu M-L, Teng C-C, Hsiao H-L, Liu C-H. Development and validation of the low-carbon literacy scale among practitioners in the Taiwanese tourism industry. Tourism Manag 2013;35:255–62.
[26] Hsieh LF, Lin LH. A performance evaluation model for international tourist hotels in Taiwan-an application of the relational network DEA. Int J Hospit Manag 2010;29(1):14–24.
[27] Huang Y, Coelho V-R. Sustainability performance assessment focusing on coral reef protection by the tourism industry in the Coral Triangle region. Tourism Manag 2017;59:510–27.
[28] Jones C. Scenarios for greenhouse gas emissions reduction from tourism: an extended tourism satellite account approach in a regional setting. J Sustain Tourism 2012;21(3):458–72.
[29] Jones C, Munday M. Exploring the environmental consequences of tourism: a satellite account approach. J Trav Res 2007;46(2):164–72.
[30] Kao C. Efficiency decomposition for parallel production systems. J Oper Res Soc 2012;63(1):64–71.
[31] Kulshreshtha M, Parikh JK. Study of efficiency and productivity growth in opencast and underground coal mining in India: a DEA analysis. Energy Econ 2002;24(5):439–53.
[32] Kelly J, Williams PW. Modeling tourism destination energy consumption and greenhouse gas emissions: Whistler, British Columbia, Canada. J Sustain Tourism 2007;15(1):67–90.
[33] Kuo NW, Chen PH. Quantifying energy use, carbon dioxide emission, and other environmental loads from island tourism based on a life cycle assessment approach. J Clean Prod 2009;17(15):1324–30.
[34] Köksala D-C, Aksu A-A. Efficiency evaluation of A-group travel agencies with data envelopment analysis (DEA): a case study in the Antalya region, Turkey. Tourism Manag 2007;28:830–4.
[35] Lai JHK. Carbon footprints of hotels: analysis of three archetypes in Hong Kong. Sustain Cities Soc 2015;14(1):334–41.
[36] Liu J, Feng T-T, Yang X. The energy requirements and carbon dioxide emissions of tourism industry of western China: a case of Chengdu city. Renew Sustain Energy Rev 2011;15:2887–94.
[37] Luo F, Becken S, Zhong YD. Changing travel patterns in China and 'carbon footprint' implications for a domestic tourist destination. Tourism Manag 2018;65(4):1–13.
[38] Medina L-F, Ignacio G-G, Sandra M-M. Measuring efficiency of sun & beach tourism destinations. Ann Tourism Res 2012;39(2):1248–51.
[39] Meng WQ, Xu LY, Hu BB, Zhou J, Wang ZL. Quantifying direct and indirect carbon dioxide emissions of the Chinese tourism industry. J Clean Prod 2016;45:586–94.
[40] Moutinho V, Costa C, Bento J-P-C. The impact of energy efficiency and economic productivity on $CO_2$ emission intensity in Portuguese tourism industries. Tourism Manag Perspect 2015;16:217–27.
[41] Oh DH. A global Malmquist-Luenberger productivity index-an application to OECD countries 1990-2004 Working paper 2009.
[42] Olesen OB, Petersen NC, Podinovski VV. Efficiency measures and computational approaches for data envelopment analysis models with ratio inputs and outputs. Eur J Oper Res 2017;261(2):640–55.
[43] Oluseyi PO, Babatunde OM, Babatunde OA. Assessment of energy consumption and carbon footprint from the hotel sector within Lagos, Nigeria. Energy Build 2016;118:106–13.
[44] Oukil A, Channouf N, Al-Zaidi A. Performance evaluation of the hotel industry in an emerging tourism destination: the case of Oman. J Hospit Tourism Manag 2016;29:60–8.
[45] Perch-Nielsen S, Sesartic A, Stucki M. The greenhouse gas intensity of the tourism sector: the case of Switzerland. Environ Sci Pol 2010;13(2):131–40.
[46] Scott D, Peeters P, Gössling S, Scott D, Becken S. Can tourism deliver its "aspirational" greenhouse gas emission reduction targets? J Sustain Tourism 2010;18(3):393–408.
[47] Sun Y-Y. A framework to account for the tourism carbon footprint at island destinations. Tourism Manag 2014;45:16–27.
[48] Sun Y-Y. Decomposition of tourism greenhouse gas emissions: revealing the dynamics between tourism economic growth, technological efficiency, and carbon emissions. Tourism Manag 2016;55:326–36.
[49] Suzuki S, Nijkamp P, Rietveld P. Regional efficiency improvement by means of data envelopment analysis through Euclidean distance minimization including fixed input factors: an application to tourist regions in Italy. Pap Reg Sci 2011;90(1):67–90.
[50] Tan Y-M, Wu C-C, Wu Z-W. Research on classification and grading indicator system

of eco-tourism zones. J Cent South Univ For Technol 2009;29:20–8.
[51] Tang CC, Zhong LS, Ng P. Factors that influence the tourism industry's carbon emissions: a tourism area life cycle model perspective. Energy Pol 2017;109:704–18.
[52] Tang Z. An integrated approach to evaluating the coupling coordination between tourism and the environment. Tourism Manag 2015;46:11–9.
[53] Tsai KT, Lin TP, Hwang RL, Huang YJ. $CO_2$ emissions generated by energy consumption of hotels and homestay facilities in Taiwan. Tourism Manag 2014;42:13–21.
[54] UNWTO. Towards a low carbon travel and tourism sector. The World Economic Forum; 2009. p. 3–36.
[55] Wang Q, Chen Y. Energy saving and emission reduction revolutionizing China's environmental protection. Renew Sustain Energy Rev 2009;14(1):535–9.
[56] Wu P, Han Y-J, Tian M. The measurement and comparative study of carbon dioxide emissions from tourism in typical provinces in China. Acta Ecol Sin 2015;35(6):184–90.
[57] Yang J-M, Wan C-Y. Progress in research on the impacts of global climate change on winter ski tourism. Adv Clim Change Res 2010;1(2):55–62.
[58] Zaman K, Shahbaz M, Loganathan N, Raza SA. Tourism development, energy consumption and environmental Kuznets curve: trivariate analysis in the panel of developed and developing countries. Tourism Manag 2016;54:275–83.
[59] Zeineldin A. The Egyptian economy in 1999: an input-output study. Econ Modell 1986;3(2):140–6.
[60] Zha J, Li Z. Drivers of tourism growth. Tourism Econ 2016;22(3):470–92.