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# The Relationship between Tourism, Carbon Dioxide Emissions, and Economic Growth in the Yangtze River Delta, China

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**Abstract:** Quantifying the dynamics of regional tourism in a low-carbon economy context is a pivotal issue to develop energy policies, and to decompose the national carbon abatement. Based on a case study approach for the Yangtze River Delta (YRD), China, the relationship between tourism, carbon dioxide (CO<sub>2</sub>) emissions, and economic growth were examined. The bottom-up approach, decoupling analysis, and Logarithmic Mean Divisia Index (LMDI) decomposition were integrated and applied. The results from 2001 to 2015 indicated that tourism-induced energy consumption and CO<sub>2</sub> emissions in YRD increased from  $896.90 \times 10^8$  MJ to  $3207.40 \times 10^8$  MJ, and  $673.55 \times 10^4$  t to  $2152.27 \times 10^4$  t, respectively. Tourism-related transport from Shanghai was the major contributor towards emissions. The decoupling relation between CO<sub>2</sub> emissions and economic growth, in general, were desirable in YRD's tourism, except in 2004. However, the situation in Shanghai was complicated. Additionally, industry size and expenditure size effect were principal factors to promote carbon emissions growth, whereas energy intensity, spatial structure, and sectorial structure had negative effects. Key issues for policymakers have been highlighted and discussed.

**Keywords:** low-carbon tourism; energy; CO<sub>2</sub>; decoupling; LMDI decomposition

## 1. Introduction

Tourism has been one of the key drivers to the anthropogenic component of global warming [1,2], which is predicted to contribute about 7.5% of global CO<sub>2</sub> emissions in 2035 [3]. Given the goal of 50% mitigation of greenhouse gases by 2050 that was established during the G8 (Group of Eight countries) summit [4], the tourism industry must substantially reduce carbon emissions and adopt a low-carbon economy approach [5,6]. However, this requires a concerted effort from all countries, and is dependent on the linkage between tourism, energy-related CO<sub>2</sub> emissions, and economic growth [7–9].

The momentum towards a low-carbon economy has become an emergent topic in tourism [10–14], as evident via numerous research focused on the following: (i) total amount of tourism-induced energy consumption and CO<sub>2</sub> emissions [15,16]; (ii) energy-related CO<sub>2</sub> emissions from tourism at different spatial scales [17,18]; (iii) assessment methods of CO<sub>2</sub> emissions from tourism [19–22]; (iv) relationships between tourism, carbon emissions, and economic development [8,23,24]; and (v) policies and counter-measures in energy savings and emissions reduction from the tourism sector and its subsectors [25–28]. While there is burgeoning research during the past decade, most studies have been limited to a singular focus within a prescribed year(s) in time, and apply survey data [9,29]. Hence, additional research is needed due to the limited quantitative understanding associated with low-carbon economy and tourism, such as:

- (i) Relative relationship between tourism-induced CO<sub>2</sub> emissions and economic growth. This can be measured by the decoupling of carbon emissions to reveal the status of tourism development within a low-carbon economy approach. Decoupling index was proposed to evaluate the connection between economic change and environmental pressures [30,31], which can also be extended to determine the link between economic development and environmental changes induced by tourism growth.
- (ii) Separate effects of tourism on CO<sub>2</sub> emissions to highlight the underlying factors to influence emissions, which can be investigated by the Logarithmic Mean Divisia Index (LMDI) decomposition method. This method has been preferred to explore the key factors that contribute to changes caused due to economic growth, environment pressures, and social development [29,32,33]. Collectively, these two issues provide a comprehensively quantitative basis to assess the linkage of tourism, carbon emissions, and economic growth. Furthermore, there is still very limited application in the use of decoupling analysis and LMDI decomposition within the tourism sector and subsectors [24,33].

The importance of energy consumption, carbon emissions and economic development in the tourism sector is currently being emphasized in large economies such as China. In 2016, the number of Chinese inbound, outbound, and on domestic routes were 138 million, 122 million, and 4.44 billion [34], which were 1.65, 11.65, and 5.96 times more than in 2000, respectively [35]. Such large-scale and continuous growth in tourism inevitably leads to substantial energy use and carbon emissions [9]. As one of the key contributors to global carbon emissions, China is faced with a major conundrum between rapid development versus emissions reduction in the quest for a low-carbon tourism economy [6,36–38].

Additionally, there is a paucity of research along with reliable findings to comprehensively assess the low-carbon tourism economy in China. More specifically, the relationships between tourism, carbon emissions, and economic growth have not been well recognized [25,39]. While recent studies on carbon emissions from the tourism sector exist at the national scale [16,39], longitudinal time-series data across various provinces, municipalities, and autonomous regions are limited [18,32,40]. Therefore, there exists a need to evaluate the low-carbon tourism economy on a regional basis in order to align towards national energy savings and emissions reduction targets [18].

Accordingly, based on a regional case study of the Yangtze River Delta (YRD), China, the purpose of this research is to explore the relationship between tourism, CO<sub>2</sub> emissions, and economic growth. Based on the integrated application of a bottom-up approach, decoupling analysis and LMDI decomposition, three main aspects are analyzed: (i) dynamics of tourism-induced energy consumption and CO<sub>2</sub> emissions; (ii) decoupling relation between CO<sub>2</sub> emissions and economic growth in tourism; and (iii) separate effects of tourism on CO<sub>2</sub> emissions. The objective is to assist in the formulation of specific and effective policies that will reduce carbon emissions due to tourism.

## 2. Literature Review

### 2.1. Tourism-Induced CO<sub>2</sub> Emissions: Scale and Method

Studies on tourism-induced CO<sub>2</sub> emissions have received academic attention over the past decade and have been examined at different spatial scales. Peeters and Dubois [41] found total CO<sub>2</sub> emissions in 2005 from tourism was 1302 Mt, which accounted for 4.95% of global emissions. UNWTO-UNEP-WMO [3] estimated that tourism-related CO<sub>2</sub> emissions contributed a range of 3.9% to 6.0% of the global emissions in 2005 (with an average of 5%). From the tourism sectors, most emissions were attributed to the travel segment, especially air transport [41–43]. At the national and regional scales, results have been determined based on different methods [16,44,45]. For example, in Cyprus, Katircioglu et al. [44] suggested that tourism had a direct and statistically significant effect on the level of energy consumption and CO<sub>2</sub> emissions for the long-term economy. In New Zealand, although top-down and bottom-up methods were based on macroeconomic data and activity-based data

respectively, by using both methods, Becken and Patterson [46] identified that the tourism sector contributed to similar annual energy use (between 25 and 28 PJ) and CO<sub>2</sub> emissions (between 1400 and 1600 kt).

Likewise, in Australia, the production approach estimated total greenhouse gas emissions to be 54.4 Mt, but an expenditure-based approach yielded 61.5 Mt [20]. In addition, in Wales, an extended tourism environmental satellite account approach found that 3.28 Mt greenhouse gas emissions were generated by the tourism sector, with tourist transportation responsible for 58.5% of the total emissions [45]. In Chengdu, western China, Liu et al. [32] used an input-output approach to calculate CO<sub>2</sub> emissions that showed 1.7–2.1 Mt. This approach was also adopted to assess tourism-induced CO<sub>2</sub> emissions in Romania [19]. Moreover, by means of a life-cycle assessment of Penghu Island in Taiwan, Kuo and Chen [22] identified that airplanes, star hotel lodging, and motorized water activity were the greatest sources of CO<sub>2</sub>. Similarly, in Iceland, by means of an input/output-based hybrid life-cycle assessment method, the total tourism GHG emissions tripled from 2010 to 2015, with air travel that accounted for 50–82% of the impact [47].

Overall, specific statistics on tourism-induced CO<sub>2</sub> emissions are missing at a country-level [44]. Further, there is still a lack of consensus among researchers as to the best method to measure tourism-induced CO<sub>2</sub> emissions [22]. Hence, the system boundaries for tourism cannot be clearly identified. However, top-down and bottom-up approaches have been extensively applied in the assessment of carbon emissions from tourism largely due to availability of data [15,18].

## 2.2. Tourism-Induced CO<sub>2</sub> Emissions in China

Several approaches have been employed to assess the CO<sub>2</sub> emissions in China's tourism industry. A preliminary attempt via a bottom-up approach was applied in 2008 [16], along with an input-output analysis [48]. Recently, a top-down approach was used to calculate the national tourism CO<sub>2</sub> emissions for 2002, 2005, 2007, and 2010 based on a combination of Tourism Satellite Account and Input-Output model [49]. Research has also been conducted at a regional level and smaller scales [50,51], such as in Jiangsu province [52] and Chengdu city [32]. Overall, while studies have evolved from the macro-scale (national) to the meso-scale (regional) and micro-scale (individual destination), additional research is needed given the need for emissions reduction in China.

Furthermore, with respect to data and methods, China has not established a complete tourism satellite account. Also, the China Energy Statistics Yearbook does not include any specific energy use items that relate to tourism [24]. This creates challenges to use a top-bottom approach as a tool for estimation. To overcome this issue, the bottom-up analysis explores detailed information on energy use and CO<sub>2</sub> emissions (for example, specific driving forces to promote emissions). This approach is able to meet the estimation requirements at the meso- or micro-scale, and is valuable in the development of energy conservation and emissions reduction strategies based on targeted industries [15].

## 2.3. Decoupling Relation between CO<sub>2</sub> Emissions and Economic Growth in Tourism

Decoupling was introduced to the environmental sciences discipline to measure the de-linking relationship between economic growth and resource consumption. When economic growth is achieved with steady or even decreased resource consumption, it relates to the general discourse of delinking from increased environmental problems [30,53]. The Organization for Economic Co-operation and Development [54] first proposed the decoupling indicator to block the connection between economic change and environmental pollution. Since then, decoupling has been redefined and has been distinguished as eight types [30,55], but indicators lack uniformity with respect to the best method [56].

Currently, the European Union has adopted the decoupling of resource use from economic growth as a policy goal [57]. This has been widely applied to assess the relationship between economy, energy use, and environment [31,58,59]. In the tourism discipline, it has been noted that a long-run equilibrium linkage exists between tourism, carbon emissions, and economic development [44].

However, as an environmental indicator for sustainable development, there is still limited applications and findings of decoupling linkage between carbon emissions and the tourism economy [24,44,60].

#### 2.4. Decomposition of CO<sub>2</sub> Emissions from Tourism Effects

The aim of decomposition is to identify the effects by which CO<sub>2</sub> emissions from tourism can be assessed along with its evolution and importance. Besides the relationship between individual tourism sectors, factors, and CO<sub>2</sub> emissions, it should also identify the directions for policies with respect to emission reductions for low-carbon development [33]. As to the decomposition methods, based on the decomposition of a differential quantity, LMDI decomposition is proposed [61,62]. The result of this method generates no residuals and accommodates the value zero in the dataset, which can overcome the key limitations with respect to traditional decomposition methods [61–64]. The LMDI has been regarded as a preferred method, and is widely adopted for the decomposition of CO<sub>2</sub> emissions in energy-economic study [65–68]. Additionally, it can play a role in the analysis to determine the separate effects on CO<sub>2</sub> emissions due to energy use by the tourism industry [23,29].

### 3. Study Area

The YRD agglomeration is comprised of the Shanghai municipality and its neighboring provinces of Jiangsu in the northwest and Zhejiang in the southwest. There are 13 cities within the jurisdiction of Jiangsu and 11 cities in Zhejiang (Figure 1). The total area of YRD is more than  $21.07 \times 10^4$  km<sup>2</sup> and accounts for 2.19% of China's land area [69]. With robust economic development, the YRD region has become one of the most important economic centers, as well as the world's sixth largest urban agglomeration.

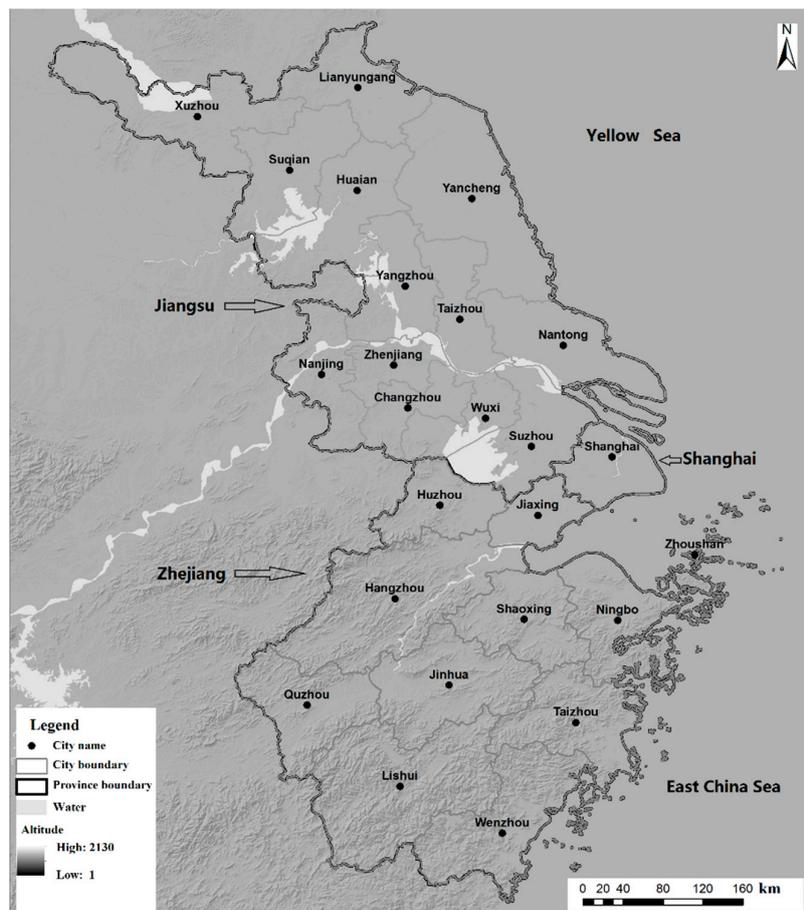


Figure 1. The study area—YRD.

Moreover, the rich cultural, historical, natural and other various tourist attractions have laid an important foundation for rapid tourism development, which is popularly known as the “golden triangle” in China [70]. The number of domestic and inbound tourist arrivals to the YRD has reached 1.42 billion and 21.17 million in 2015 [71], with an annual rate of growth at 13.88% and 10.32% compared with 2001, respectively [72–74]. Given the popularity and immense tourism growth, this region was chosen for this study to assess energy savings and emissions reduction from tourism. Moreover, given the region’s important status, achieving a low-carbon economy will offer significant contributions for the whole country.

#### 4. Materials and Methods

##### 4.1. Bottom-Up Approach

The tourism industry encompasses both direct and indirect energy consumption and carbon emissions. Direct energy use is derived from fossil fuels such as coal, oil, and natural gas, while the indirect is rooted in the production of various types of intermediate products for the tourism industry [16,32]. Hence, when accounting for environmental impacts, it is pragmatic to focus on tourism-related industries [16,39,46] as carbon sources mainly originate from three sectors (i.e., transport, accommodation, and activities) [3]. Thus, in this paper, direct energy use and carbon emissions were calculated along with a bottom-up approach as it begins with tourist data at the destination. The formula for direct energy consumption and carbon dioxide emissions from the aforementioned three tourism sectors is expressed as follows:

$$E_t = \sum_{j=1}^3 E_{jt} = E_{1t} + E_{2t} + E_{3t}, \quad (1)$$

$$C_t = \sum_{j=1}^3 C_{jt} = C_{1t} + C_{2t} + C_{3t}, \quad (2)$$

where  $E_t$  and  $C_t$  indicate the amount of direct energy use and CO<sub>2</sub> emissions from tourism in year  $t$  from YRD;  $E_{jt}$  is the energy consumption of the three tourism sectors, that is, tourism transport ( $E_{1t}$ ), accommodation ( $E_{2t}$ ), and activities ( $E_{3t}$ ); and  $C_{jt}$  denotes the CO<sub>2</sub> emissions generated by tourism transport ( $C_{1t}$ ), accommodations ( $C_{2t}$ ), and activities ( $C_{3t}$ ), respectively.

##### 4.1.1. Tourism Transport

$$E_{1t} = \sum_{i=1}^3 \sum_{s=1}^4 D_{ist} * F_s * \alpha_s, \quad (3)$$

$$C_{1t} = \sum_{i=1}^3 \sum_{s=1}^4 D_{ist} * F_s * \beta_s, \quad (4)$$

where  $i$  is the sub-regions in YRD—Jiangsu, Zhejiang and Shanghai;  $s$  is the transport mode (that is, airlines, highways, railways, waterways);  $D_{ist}$  is the passenger turnover volume for each transport mode  $s$ ;  $F_s$  indicates the proportion of tourists as passengers for each transport mode  $s$ ;  $\alpha_s$  denotes the energy consumption per unit for transport mode  $s$  (MJ/pkm);  $\beta_s$  is the CO<sub>2</sub> emissions per unit for transport mode  $s$  (g/pkm).

Since China does not have a complete tourism satellite account system or data, previous studies [24,75] led to estimates for  $F_s$  to be 64.7% (airlines), 13.8% (highways), 31.6% (railways), and 10.6% (waterways). Based on the academic literature (see Becken et al. [42]; Carlsson-Kanyama and Lindén [76]; Lenzen [77]), energy consumption per unit for the transportation modes ( $\alpha_s$ ) as 2 MJ/pkm for airlines, 1.8 MJ/pkm for highways, 1 MJ/pkm for railways, and 0.9 MJ/pkm for

waterways were utilized. Carbon dioxide emissions per unit ( $\beta_s$ ) were determined based on previous studies, and the actual situation in China relate to 137, 133, 27, and 106 g/pkm for airlines, highways, railways, and waterways, respectively [16,24,41].

#### 4.1.2. Accommodation

$$E_{2t} = \sum_{i=1}^3 G_{it} * Q_{it} * \delta, \quad (5)$$

$$C_{2t} = \sum_{i=1}^3 G_{it} * Q_{it} * \gamma * \frac{44}{12}, \quad (6)$$

where  $G_{it}$  is the total number of beds in hotels to reflect the accommodation scale;  $Q_{it}$  is the annual letting rate;  $\delta$  is the energy consumption per bed night;  $\gamma \times (44/12)$  represents the CO<sub>2</sub> emissions per bed night.  $\delta$  was estimated as 130 MJ per bed night with regards to the hotel industry globally [78]. However, in combination with previous studies (see Wu and Shi [16]; Kuo and Chen [22]), we formulated  $\delta = 155$  MJ/bed night since there is a lower proportion of green hotels and higher energy consumption hotels in China.  $\gamma$  is 43.2 g C/MJ, that is, the conversion coefficient established by the World Power Organization [24]. In addition, 44/12 is the proportion of the molecular weight of CO<sub>2</sub> to that of C atoms.

#### 4.1.3. Tourism Activities

$$E_{3t} = \sum_{i=1}^3 \sum_{x=1}^5 K_{it} * P_{xt} * \lambda_x, \quad (7)$$

$$C_{3t} = \sum_{i=1}^3 \sum_{x=1}^5 K_{it} * P_{xt} * \tau_x, \quad (8)$$

where  $K_{it}$  is the tourist number;  $P_{xt}$  denotes the proportion of tourists choosing an activity type  $x$ . In China, tourism activity was divided into five main types, that is, sightseeing, leisure vacations, business conferences, visiting relatives/friends, and others.  $\omega_x$  indicates the energy consumption per unit for activity type  $x$ ;  $\tau_x$  is the CO<sub>2</sub> emissions per unit for activity type  $x$ .

We set up the energy consumption per unit ( $\omega_x$ ) as 8.5, 26.5, 16, 12, and 3.5 MJ/visitor, and CO<sub>2</sub> emissions per unit ( $\tau_x$ ) as 417, 1670, 786, 591, and 172 g/visitor for the above activities, respectively. These were based on Wu and Shi [16] as they first assessed the Chinese energy use and CO<sub>2</sub> emissions among different tourism activity purposes. Further, it is important to note that in this study the coefficients of energy use and CO<sub>2</sub> emissions were constant. Although technological changes occur continuously with time, these changes were minuscule and can be ignored during the short time period from 2001 to 2015, when compared with the macro-changes in tourism-induced energy use and CO<sub>2</sub> emissions.

#### 4.2. Decoupling Index

According to Tapio [30], the decoupling index ( $L_D$ ) of CO<sub>2</sub> emissions from the economic development in tourism sector can be assessed as Equation (9):

$$L_D = \frac{\% \Delta L_{CO_2}}{\% \Delta L}, \quad (9)$$

where  $\% \Delta L_{CO_2}$  and  $\% \Delta L$  are the change rate of CO<sub>2</sub> emissions and economic development generated from the tourism sector between a base and target year. The  $L_D$  classification and its relationship with sustainability are listed in Table 1.

**Table 1.** The classification of the decoupling state and its relationship with sustainability.

State	% $\Delta L_{CO_2}$	% $\Delta L$	$L_D$	Relationship with Sustainability
Strong decoupling	<0	>0	<0	The best state towards sustainability under the low-carbon tourism economy.
Weak decoupling	>0	>0	$0 < L_D < 1$	The state is desirable.
Negative decoupling	>0	>0	>1	The state is not favorable for sustainability.
Recessive decoupling	<0	<0	>1	The state is not favorable for sustainability.
Weak negative decoupling	<0	<0	$0 < L_D < 1$	The state is not favorable for sustainability.
Strong negative decoupling	>0	<0	<0	The worst state towards sustainability under the low-carbon tourism economy.

Source: Revised from Tapio [30] and Vehmas et al. [57].

#### 4.3. The Kaya Identity and LMDI Decomposition Model

The Kaya identity [79] is an equation that explores the underlying factors with respect to the impact of human activities on CO<sub>2</sub> emissions [32]. This can be extended to explore the effects of tourism on CO<sub>2</sub> emissions. The formula is expressed as

$$C = \sum_i \sum_j \left( \frac{C_{ij}}{E_{ij}} * \frac{E_{ij}}{E_i} * \frac{E_i}{R_i} * \frac{R_i}{R} * \frac{R}{P} * P \right), \quad (10)$$

where  $C$  denotes the total tourism-induced CO<sub>2</sub> emissions;  $C_{ij}$  represents the CO<sub>2</sub> emissions from the region  $i$ , tourism sector  $j$ ;  $E_{ij}$  is the energy consumption from the region  $i$ , tourism sector  $j$ ;  $E_i$  is the total tourism-induced energy consumption from the region  $i$ ;  $R_i$  is the economic growth from the region  $i$ ;  $R$  is the total tourism economy;  $P$  is the total number of tourist arrivals. Let

$$A_{ij} = \frac{C_{ij}}{E_{ij}}, B_{ij} = \frac{E_{ij}}{E_i}, D_i = \frac{E_i}{R_i}, F_i = \frac{R_i}{R}, I = \frac{R}{P}, k = P, \quad (11)$$

Six driving factors are noted: emission coefficient effect ( $A_{ij}$ ); sectorial structure effect ( $B_{ij}$ ); energy intensity effect ( $D_i$ ); spatial structure effect ( $F_i$ ); expenditure size effect ( $I$ ); and industry size effect ( $k$ ).

The additive LMDI is then applied for the decomposition of tourism-induced CO<sub>2</sub> emissions to those driving factors. The change of CO<sub>2</sub> emissions can be expressed as Equation (12):

$$\Delta C = C^T - C^0, \quad (12)$$

where  $\Delta C$  is the change between year 0 with year  $T$ ;  $C^0$  and  $C^T$  are the emissions in year 0 and  $T$ , respectively. Then,  $\Delta C$  can be further illustrated as Equation (13):

$$\Delta C = \Delta C_{A_{ij}} + \Delta C_{B_{ij}} + \Delta C_{D_i} + \Delta C_{F_i} + \Delta C_I + \Delta C_k, \quad (13)$$

Then, based on the LMDI, each factor in Equation (13) can be further expressed as follows [63,80,81]:

$$\begin{aligned} \Delta C_{A_{ij}} &= \sum_i \sum_j \left( \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \right) * \ln \left( \frac{A_{ij}^T}{A_{ij}^0} \right) & \Delta C_{B_{ij}} &= \sum_i \sum_j \left( \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \right) * \ln \left( \frac{B_{ij}^T}{B_{ij}^0} \right), \\ \Delta C_{D_i} &= \sum_i \sum_j \left( \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \right) * \ln \left( \frac{D_i^T}{D_i^0} \right) & \Delta C_{F_i} &= \sum_i \sum_j \left( \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \right) * \ln \left( \frac{F_i^T}{F_i^0} \right), \\ \Delta C_I &= \sum_i \sum_j \left( \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \right) * \ln \left( \frac{I^T}{I^0} \right) & \Delta C_k &= \sum_i \sum_j \left( \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \right) * \ln \left( \frac{k^T}{k^0} \right), \end{aligned} \tag{14}$$

The carbon coefficient is usually constant in practice, therefore, the emission coefficient effect ( $\Delta C_{A_{ij}}$ ) is always 0 in the process of decomposition [65], which can be ignored in the analysis. Collectively, a research framework was formulated with the integration of methods for a bottom-up approach, decoupling analysis and LMDI decomposition to measure tourism development towards a low-carbon economy (Figure 2).

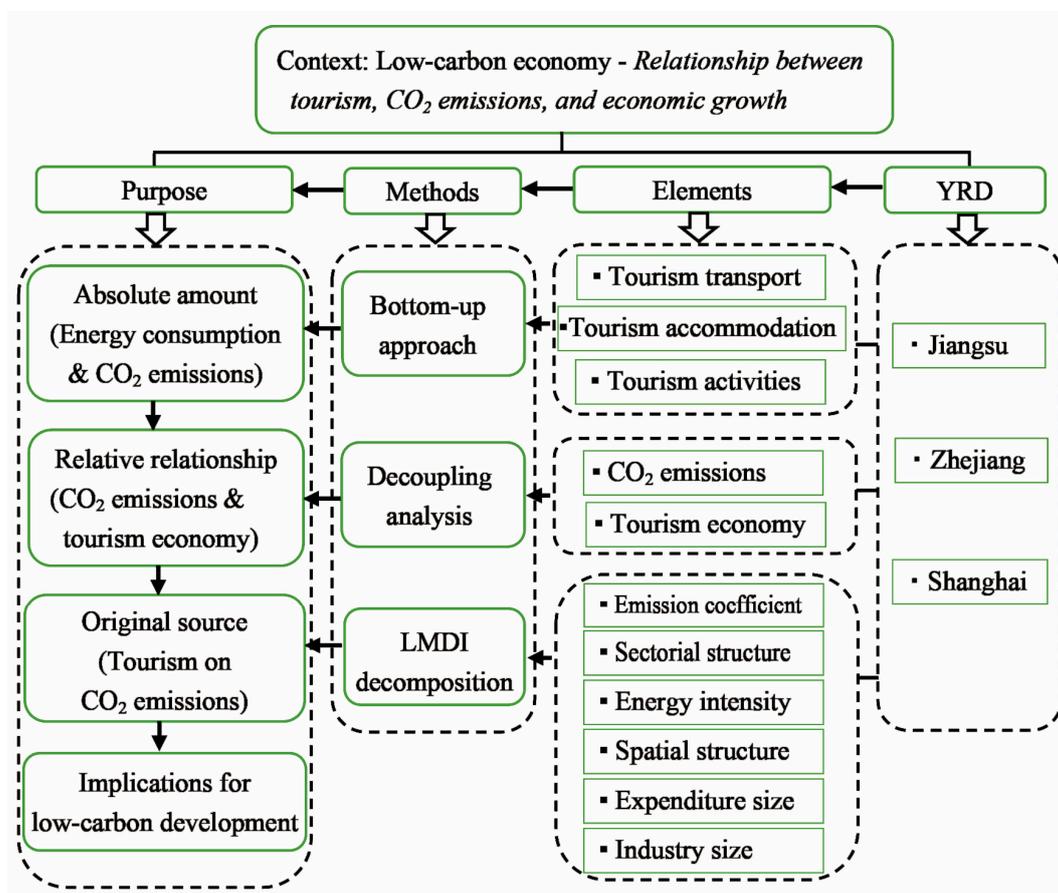


Figure 2. Research Framework.

#### 4.4. Data Sources

The time series from 2001 to 2015 were selected due to data accessibility. During this time period, three phases of a Five-Year Plan was developed in China from 2001–2005 (10th Five-Year Plan), 2006–2010 (11th Five-Year Plan), and 2011–2015 (12th Five-Year Plan). Such plans are formulated to address national priorities to ensure development of the national economy and society in the country. During the execution of each plan period, the policies are stabilized, and tend to have subsequent impacts for the next plan.

The sources of data for Jiangsu, Zhejiang, and Shanghai (YRD) include the following: (1) tourist passenger turnover volume, tourist arrivals, tourism foreign exchange, and domestic tourism revenues. These were collected from the Statistical Yearbook of Jiangsu, Zhejiang, and Shanghai (2002–2016), and the statistical bulletin on the national economic and social development of Jiangsu, Zhejiang, and Shanghai (2002–2016). The quantity of beds and occupancy rate in star-rated hotels were extracted from the Yearbook of China Tourism Statistics (2002–2016). (2) Data for inbound tourist arrivals and domestic tourist arrivals; percentage of urban/rural tourist arrivals; and activity percentage for leisure vacations, business conferences, visiting relatives/friends, sightseeing, and others of urban/rural tourist arrivals were also compiled. These were obtained from the sample survey information of inbound tourists (2002–2009) [82], tourism sample survey information (2010–2016) [83], Chinese tourism statistical bulletin (2002–2016), and Chinese domestic tourism sample survey information (2002–2016) [84].

## 5. Results

### 5.1. Tourism-Induced Energy Consumption and CO<sub>2</sub> Emissions in the YRD

#### 5.1.1. Total Amount in YRD

The total tourism-induced energy consumption in the YRD was  $896.90 \times 10^8$  MJ in 2001, and then illustrated a trend of rapid increase until it reached  $3207.40 \times 10^8$  MJ in 2015, which was threefold (Table 2). The proportion of energy consumption from tourism transport was the largest and remained above 85% annually, as well as exceeded 90% in 2010 and 2011. Energy consumption from tourism accommodations experienced a remarkable increase; it rose from  $106.97 \times 10^8$  MJ in 2001 to the peak value of  $201.60 \times 10^8$  MJ in 2007, and then experienced a continuous decrease to  $138.19 \times 10^8$  MJ in 2015. In general, the proportion of energy consumed by tourism accommodations decreased from 11.93% in 2001 to 4.31% in 2015. In contrast, the tourism activities consumed more energy from 2001–2015, indicated by its rapid rise from  $138.00 \times 10^8$  MJ to  $258.67 \times 10^8$  MJ, consequently resulted in its proportion in the whole energy consumption to exceed tourism accommodations, and increase to 8.06% in 2015.

**Table 2.** The total amount of energy consumption and CO<sub>2</sub> emissions from tourism in the YRD (2001–2015).

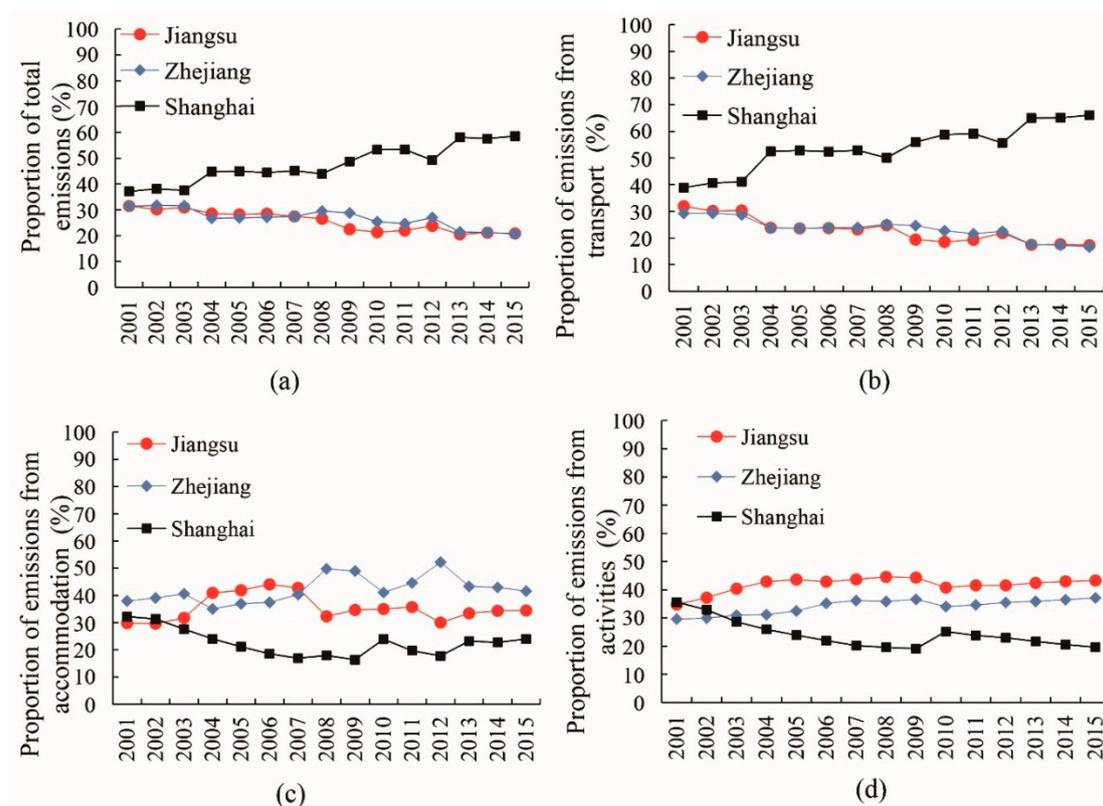
Year	Energy Consumption (10 <sup>8</sup> MJ)				CO <sub>2</sub> Emissions (10 <sup>4</sup> t)			
	E <sub>1</sub>	E <sub>2</sub>	E <sub>3</sub>	Total	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	Total
2001	760.85	106.97	29.09	896.90	488.70	169.44	15.41	673.55
2002	856.45	120.24	33.40	1010.09	551.46	190.46	17.64	759.57
2003	897.12	122.86	33.52	1053.50	580.57	194.60	17.65	792.83
2004	1288.31	183.92	41.12	1513.35	838.94	291.33	21.57	1151.84
2005	1428.85	182.13	47.45	1658.43	933.48	288.50	24.88	1246.86
2006	1611.26	188.65	55.72	1855.64	1055.28	298.83	29.24	1383.35
2007	1929.21	201.60	63.77	2194.58	1268.93	319.34	33.36	1621.63
2008	1994.38	171.46	72.36	2238.20	1311.01	271.59	38.20	1620.79
2009	2100.63	168.30	85.11	2354.03	1380.84	266.58	45.32	1692.74
2010	2450.10	152.87	112.61	2715.58	1606.73	242.15	60.49	1909.37
2011	2666.14	146.98	138.00	2951.12	1747.28	232.81	75.46	2055.54
2012	2614.91	173.60	161.63	2950.13	1705.75	274.98	88.48	2069.22
2013	2531.50	138.29	177.66	2847.45	1621.62	219.04	97.59	1938.25
2014	2685.06	137.55	239.57	3062.18	1704.57	217.88	139.54	2061.99
2015	2810.54	138.19	258.67	3207.40	1782.62	218.89	150.76	2152.27

Note: E<sub>1</sub>, E<sub>2</sub>, and E<sub>3</sub> represent EC of tourism transport, accommodation, and activities, respectively. C<sub>1</sub>, C<sub>2</sub>, and C<sub>3</sub> are the CE of tourism transport, accommodation, and activities.

The trend of CO<sub>2</sub> emissions from tourism was similar to energy consumption for the total region. In 2001, tourism emitted  $673.55 \times 10^4$  t CO<sub>2</sub> and reached  $2152.27 \times 10^4$  t in 2015, with an average annual increase of 8.65%. As for the three tourism sectors, transport was responsible for the greatest proportion of CO<sub>2</sub> emissions, with an increase from 72.56% in 2001 to its peak value of 85.00% in 2011, and then a decrease to 82.83% in 2015. The amount of emissions from tourism accommodations experienced fluctuations, but a proportion showed a significant decrease of 14.99% for the research period. Compared with accommodations, although tourism activities contributed the least to CO<sub>2</sub> emissions, their share continued to illustrate increases by 4.72% over 15 years.

### 5.1.2. Comparison within the YRD

Within the YRD, CO<sub>2</sub> emissions from tourism in both Jiangsu and Zhejiang increased initially and then declined, while emissions increased rapidly in Shanghai. As illustrated in Figure 3a,b, the proportion of Shanghai's CO<sub>2</sub> emissions from tourism not only increased quickly, but also contributed the most within the whole region, which was mainly from tourism transport. In Shanghai, tourism transport emitted  $190.0 \times 10^4$  t CO<sub>2</sub> in 2001, which increased to  $1177.9 \times 10^4$  t CO<sub>2</sub> in 2015. The key factor was due to the huge turnover volume of tourist arrivals via civil aviation. This led to an increase from 13.02 billion pkm in 2001 to 83.64 billion pkm in 2015, which was 11.22 times and 7.65 times more than for Jiangsu and Zhejiang respectively. Hence, Shanghai emitted the most CO<sub>2</sub> through aviation.



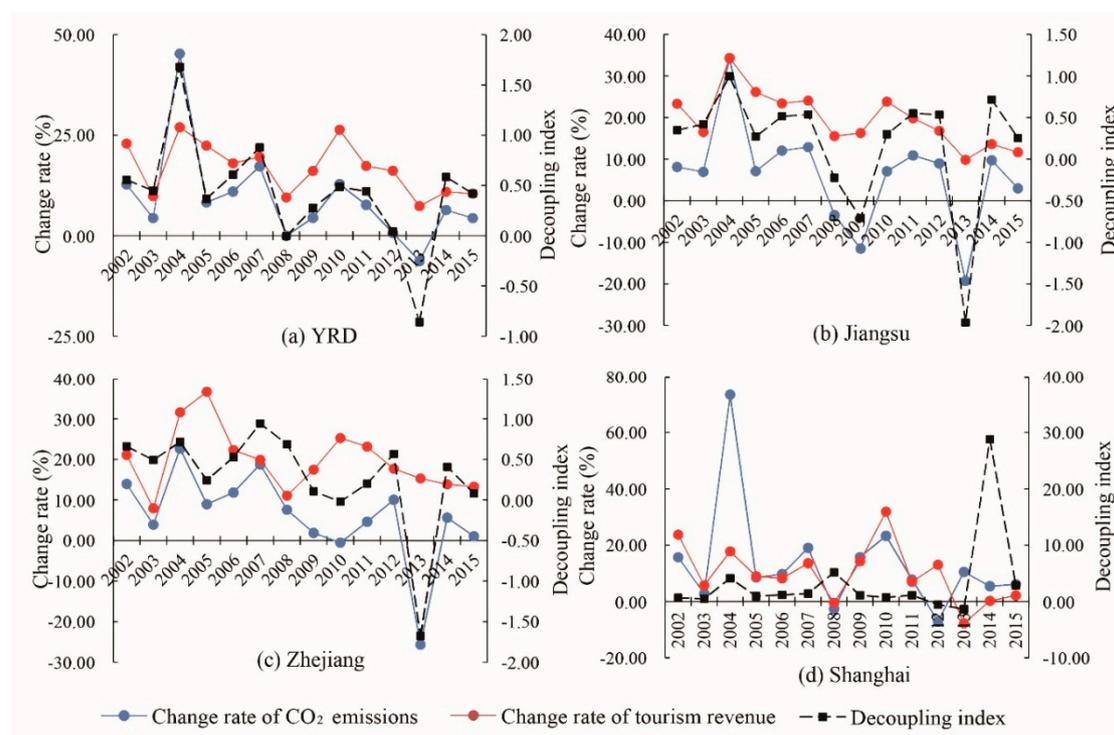
**Figure 3.** The proportion of CO<sub>2</sub> emissions from tourism sectors within YRD (2001–2015). (a) Proportion of emissions from tourism; (b) Proportion of emissions from tourism transport; (c) Proportion of emissions from accommodation; (d) Proportion of emissions from tourism activities.

Compared with transport, tourism accommodations for Zhejiang and Jiangsu contributed the most CO<sub>2</sub> emissions in the whole region largely due to the increase in the scale of accommodations. Since 2008, Zhejiang's tourism accommodations emitted more CO<sub>2</sub> than Jiangsu and Shanghai.

With respect to tourism activities, Jiangsu bears the most responsibility for emissions due to its huge number of inbound tourist arrivals, and substantial growth in leisure vacations (Figure 3c,d). According to survey data, the percentage of leisure vacations and business conferences participated by inbound arrivals increased between 2001 and 2015, with an escalation in the percentage of leisure vacations by nearly six times. Additionally, Jiangsu's inbound tourist arrivals increased rapidly from 80.75 million in 2001 to 619.34 million in 2015, which was significantly more than in Zhejiang and Shanghai.

## 5.2. Decoupling of CO<sub>2</sub> Emissions from YRD's Tourism Economy

According to Equation (9), the decoupling of CO<sub>2</sub> emissions from the YRD's tourism economy is shown in Figure 4a. For YRD, negative decoupling only existed in 2004, which illustrated a higher growth rate of CO<sub>2</sub> emissions and lower tourism economic efficiency. However, weak decoupling occurred in 2002–2003, 2005–2007, 2009–2012, and 2014–2015, which showed that the growth rate of tourism economy was higher than that of CO<sub>2</sub> emissions, as decoupling states were desirable. Furthermore, the growth rates of CO<sub>2</sub> emissions were negative, while those for tourism economic growth were positive and led to strong decoupling in 2008 and 2013. This was the best state for tourism within the context of a low-carbon economy.



**Figure 4.** The decoupling relation between CO<sub>2</sub> emissions and YRD's tourism economy. (a) Decoupling relation in the YRD; (b) Decoupling relation in Jiangsu; (c) Decoupling relation in Zhejiang; (d) Decoupling relation in Shanghai.

Within the YRD, there was a similar decoupling trend at Jiangsu and Zhejiang. In Jiangsu, the decoupling states rotated between being weak (that is, 2002–2007, 2010–2012, 2014–2015) and strong (that is, 2008–2009, 2013) (Figure 4b). Likewise, in Zhejiang, the decoupling states were largely weak (that is, 2002–2009, 2011–2012, 2013, 2014–2015), and strong in 2010 (Figure 4c). However, the situation in Shanghai was complicated and the results (Figure 4d) show weak decoupling in 2002, 2003, 2005, and 2010; negative decoupling in 2004, 2006, 2007, 2009, 2011, 2014, and 2015; recessive decoupling in 2008; strong decoupling in 2012; and strong negative decoupling in 2013. In general,

the decoupling states were desirable in general for tourism sustainability from 2001–2015 under the low-carbon economy in Jiangsu and Zhejiang. Conversely, the situation in Shanghai was scarcely any better, with 64.28% of decoupling states unfavorable for tourism.

### 5.3. Separate Effects of Tourism on CO<sub>2</sub> Emissions

Based on the LMDI decomposition, the separate effects of tourism on CO<sub>2</sub> emissions were shown in Tables 3 and 4. The change in CO<sub>2</sub> emissions of tourism from 2001 to 2015 in YRD was  $1188.94 \times 10^4$  t as the promotion effects of tourism were significantly greater than the inhibitory effects. The tourism industry size was the primary driving force, which caused emissions to improve by  $2266.54 \times 10^4$  t during the 15-year period; 1.91 times as much as the total emissions change resulted from all the influencing factors. The second contributing factor was expenditure size that enhanced CO<sub>2</sub> emissions to  $370.10 \times 10^4$  t. In contrast, energy intensity, spatial structure, and sectorial structure aided emission reduction with a decrease of  $951.90 \times 10^4$  t,  $396.18 \times 10^4$  t, and  $99.62 \times 10^4$  t, respectively (Table 3).

**Table 3.** The decomposition of CO<sub>2</sub> emissions from tourism in the YRD (2001–2015).

Factor	Sector	2001–2005	2006–2010	2011–2015	2001–2015
Industry size/ $10^4$ t	J <sub>T</sub>	488.51	1020.59	757.44	2266.54
	J <sub>1</sub>	360.77	824.41	636.63	1821.81
	J <sub>2</sub>	117.35	169.13	81.52	368.00
	J <sub>3</sub>	10.38	27.05	39.29	76.72
Expenditure size/ $10^4$ t	J <sub>T</sub>	196.41	42.59	131.10	370.10
	J <sub>1</sub>	145.05	31.36	110.19	286.61
	J <sub>2</sub>	47.18	10.20	14.11	71.49
	J <sub>3</sub>	4.18	1.03	6.80	12.00
Energy intensity/ $10^4$ t	J <sub>T</sub>	−272.90	−296.50	−382.50	−951.90
	J <sub>1</sub>	−49.48	−182.14	−253.24	−484.86
	J <sub>2</sub>	−219.29	−98.73	−88.23	−406.25
	J <sub>3</sub>	−4.13	−15.63	−41.03	−60.79
Spatial structure/ $10^4$ t	J <sub>T</sub>	−13.25	−59.96	−322.98	−396.18
	J <sub>1</sub>	−22.58	−63.06	−330.15	−415.79
	J <sub>2</sub>	8.74	2.77	0.63	12.14
	J <sub>3</sub>	0.59	0.33	6.55	7.47
Sectorial structure/ $10^4$ t	J <sub>T</sub>	2.04	−84.06	−17.60	−99.62
	J <sub>1</sub>	6.13	34.76	−59.07	−18.18
	J <sub>2</sub>	−2.73	−136.29	−21.95	−160.97
	J <sub>3</sub>	−1.35	17.47	63.42	79.53
Total/ $10^4$ t	J <sub>T</sub>	400.82	622.66	165.46	1188.94
	J <sub>1</sub>	439.90	645.33	104.36	1189.59
	J <sub>2</sub>	−48.75	−52.92	−13.92	−115.59
	J <sub>3</sub>	9.67	30.24	75.02	112.76

Notes: J<sub>T</sub>: tourism industry; J<sub>1</sub>: tourism transport; J<sub>2</sub>: tourism accommodation; J<sub>3</sub>: tourism activities.

#### 5.3.1. Industry Size Effect

During China's three Five-Year Plan periods, due to the industry size effect, CO<sub>2</sub> emissions increased to  $488.51 \times 10^4$  t,  $1020.59 \times 10^4$  t, and  $757.44 \times 10^4$  t. In 2015, the YRD hosted 1.44 billion tourists, which was six times as much as in 2001, and represented an annual geometric growth rate of 13.7%. The rapid increase in tourists requires a higher consumption of energy and, thus, more CO<sub>2</sub> would be emitted, which corresponds with tourism expansion in the YRD.

The increased CO<sub>2</sub> emissions from tourism transport accounted for 73.85%, 80.78%, and 84.05% of the total led by the industry size effect during three periods. Moreover, from the perspective of sub-regions (Table 4), the industry size promoted CO<sub>2</sub> emissions for all tourism sectors in each

sub-region between 2001 and 2015. Especially, the CO<sub>2</sub> emissions of tourism transport in Shanghai accounted for the largest share in changes within the whole industry size effect (34.38%, 45.10%, and 52.66%, in each period).

### 5.3.2. Expenditure Size Effect

During the three plan periods, the expenditure size effect contributed  $196.41 \times 10^4$  t,  $42.59 \times 10^4$  t, and  $131.10 \times 10^4$  t of CO<sub>2</sub>, respectively. Accordingly, the average tourist expenditure in the YRD rose from 962 RMB/year in 2001 to 1354 RMB/year in 2015. Although there were some fluctuations during 2008–2010 due to unexpected events such as the Asian financial crisis, overall, the expenditure maintained an annual growth rate of 2.47%. Similarly, the expenditure size had positive effects on CO<sub>2</sub> emissions from all tourism sectors. The tourism transport was the most affected, especially Shanghai which had the largest share within the entire expenditure size effect.

**Table 4.** The decomposition of CO<sub>2</sub> emissions from tourism within the YRD (2001–2015).

Year	Sub-Region	Sector	Industry Size/10 <sup>4</sup> t	Expenditure Size/10 <sup>4</sup> t	Energy Intensity/10 <sup>4</sup> t	Spatial Structure/10 <sup>4</sup> t	Sectorial Structure/10 <sup>4</sup> t
2001–2005	Jiangsu	J <sub>1</sub>	98.43	39.57	−84.91	27.76	−16.42
		J <sub>2</sub>	42.61	17.13	−36.76	12.02	35.44
		J <sub>3</sub>	4.11	1.65	−3.55	1.16	2.20
	Zhejiang	J <sub>1</sub>	94.39	37.95	−73.84	20.49	−3.05
		J <sub>2</sub>	44.21	17.78	−202.40	9.60	5.21
		J <sub>3</sub>	3.25	1.31	−2.55	0.71	0.86
	Shanghai	J <sub>1</sub>	167.96	67.53	109.28	−70.82	25.60
		J <sub>2</sub>	30.53	12.28	19.87	−12.87	−43.37
		J <sub>3</sub>	3.02	1.21	1.96	−1.27	−4.41
2006–2010	Jiangsu	J <sub>1</sub>	171.95	6.54	−159.88	19.38	13.81
		J <sub>2</sub>	67.07	2.55	−62.36	7.56	−61.73
		J <sub>3</sub>	11.28	0.43	−10.49	1.27	9.21
	Zhejiang	J <sub>1</sub>	192.16	7.31	−14.09	5.96	13.25
		J <sub>2</sub>	66.41	6.29	−35.74	2.06	−47.59
		J <sub>3</sub>	9.34	0.36	−5.03	0.29	5.00
	Shanghai	J <sub>1</sub>	460.30	17.51	−8.17	−88.40	7.70
		J <sub>2</sub>	35.65	1.36	−0.63	−6.85	−26.96
		J <sub>3</sub>	6.42	0.24	−0.11	−1.23	3.26
2011–2015	Jiangsu	J <sub>1</sub>	116.46	20.16	−129.49	20.23	−22.53
		J <sub>2</sub>	28.64	4.96	−31.84	4.97	−14.50
		J <sub>3</sub>	16.72	2.89	−18.59	2.90	26.98
	Zhejiang	J <sub>1</sub>	121.28	20.99	−207.40	45.78	−28.43
		J <sub>2</sub>	35.15	6.08	−60.11	13.27	−7.17
		J <sub>3</sub>	14.15	2.45	−24.20	5.34	29.57
	Shanghai	J <sub>1</sub>	398.88	69.04	83.65	−396.16	−8.10
		J <sub>2</sub>	17.74	3.07	3.72	−17.62	−0.29
		J <sub>3</sub>	8.41	1.46	1.76	−1.70	6.87

Notes: J<sub>1</sub>: tourism transport; J<sub>2</sub>: tourism accommodation; J<sub>3</sub>: tourism activities.

### 5.3.3. Energy Intensity Effect

The tourism energy intensity refers to the energy consumed by unit tourism revenue in a region, and reflects the overall efficiency of energy economic activities [39]. The energy intensity effect has assisted in the reduction of  $272.90 \times 10^4$  t,  $296.50 \times 10^4$  t, and  $382.50 \times 10^4$  t CO<sub>2</sub> during the three-year period. Moreover, CO<sub>2</sub> emissions from all tourism sectors decreased due to the energy intensity effect in each period, which reflected that the production of unit revenue required less energy, and the efficiency of energy use improved in YRD.

From the sub-regions, reduction in CO<sub>2</sub> emissions within the three tourism sectors due to energy intensity effect continually occurred in both Jiangsu and Zhejiang. However, during 2001–2005 and

2011–2015, the energy intensity effect led to increased CO<sub>2</sub> emissions for all tourism sectors in Shanghai, instead of any reduction. This illustrated that tourism energy efficiency in Shanghai was not high enough to assist with CO<sub>2</sub> reduction.

#### 5.3.4. Spatial Structure Effect

The spatial structure is the proportion of sub-regional tourism revenue in the total tourism revenue, which indicates the spatial distribution of development from the aspect of the tourism economy. It is the second important driving force in favor of the total  $396.18 \times 10^4$  t CO<sub>2</sub> emissions reduction in the YRD. However, it has a negative effect on CO<sub>2</sub> emissions from tourism transport with a huge decrease of  $415.79 \times 10^4$  t, while a positive effect with an increase of  $12.14 \times 10^4$  t and  $7.47 \times 10^4$  t CO<sub>2</sub> from tourism accommodation and activities. As to the sub-regions, the proportion of tourism revenues of Jiangsu, Zhejiang, and Shanghai changed from 32.53%, 25.68%, and 41.79% in 2001 to 46.08%, 36.61%, and 17.31% in 2015, respectively. This process of spatial structure change resulted in the reduction of CO<sub>2</sub> emissions from the three tourism sectors, especially for tourism transport in Shanghai, thus, effectively contributing to the total emissions reduction in YRD.

#### 5.3.5. Sectorial Structure Effect

The negative effect of sectorial structure on CO<sub>2</sub> emissions substantially decreased, which reduced CO<sub>2</sub> emissions for tourism transport ( $-18.18 \times 10^4$  t) and accommodations ( $-160.97 \times 10^4$  t), but promoted emissions of tourism activities ( $79.53 \times 10^4$  t) during 2001–2015. In fact, China has implemented the energy savings and emissions reduction strategy with adjustment in the industrial structure [85], and the tourism structure also changed over time, which led to the complicated effect on emissions [86]. In each sub-region, there was no uniform effect of sectorial structure on CO<sub>2</sub> emissions for different sectors in 2001–2005. During 2006–2010 and 2011–2015, the sectorial structure assisted to contribute towards CO<sub>2</sub> emissions in tourism activities, and reduced for accommodations. Moreover, it was evident that the sectorial structure effect demonstrated a decline, and a movement from a positive to a negative role in the CO<sub>2</sub> emissions for tourism transport.

## 6. Discussion

A low-carbon economy is the best alternative for the tourism industry in China to contribute towards energy conservation and emissions reduction at the national and global scale. Additionally, while numerous policies have been implemented in China for low-carbon economy development (for example, 12th Five-year Plan 2011–2015, and China's Policies and Actions for Addressing Climate Change 2011 [6]), there are major differences in the level and trend among the regional economy and tourism industry due to spatial disequilibrium of development. Thus, it is reasonable and necessary to decompose the national goal of emission reduction and low-carbon development to specific regions.

In this study, a bottom-up method was selected to assess the total amount of energy consumption and CO<sub>2</sub> emissions, which was the premise to clarify the relationship between regional tourism development and environmental pressures led by CO<sub>2</sub> emissions. Accordingly, tourism-induced energy consumption and CO<sub>2</sub> emissions in YRD increased. It is worth noting that tourism transport was the major contributor to the total energy consumption (>85%) and CO<sub>2</sub> emissions (>72%) from 2001 to 2015. Although there are differences between regions and countries [45,87,88] due to calculation methods, the ratios of CO<sub>2</sub> emissions from the three tourism sectors (i.e., tourism transport, accommodation, and activities) in the YRD were close enough to global tourism rates (see UNWTO-UNEP-WMO [3]). Moreover, due to the tremendous increase in CO<sub>2</sub> emitted by tourism transport in Shanghai, the ratio of the three sectors changed to be consistent with the entire Chinese tourism industry (see Tang et al. [24]).

Decoupling analysis has been demonstrated as a proper method to measure the connection between economic activity and CO<sub>2</sub> emissions [56]. This was illustrated in this study as the complex dynamics of decoupling states between the tourism economic growth and CO<sub>2</sub> emissions in the YRD

was noted. Weak decoupling occurred during various years along with fluctuations of negative decoupling and strong decoupling. It reflected that the tourism economic expansion was not always positive with the change of CO<sub>2</sub> emissions, which can broaden our vision of the relationship between tourism and CO<sub>2</sub> emissions [9,89]. In general, the decoupling state during 2001–2015 was deemed desirable with respect to a low-carbon tourism economy, except in 2004 due to the negative decoupling. Meanwhile, weak decoupling in most years proved that more efficient technology should be applied to further decrease CO<sub>2</sub> emissions [57]. Thus, the ideal tourism economic development could be achieved with decreased environmental stress.

To further understand how tourism impacts CO<sub>2</sub> emissions, the LMDI decomposition method was used in the final step, which was the most important aspect to assist policy-makers to identify key factors and formulate policies for emission reduction. First, industry size and expenditure size were primary factors to contribute towards tourism-induced CO<sub>2</sub> emissions in YRD and its sub-regions, which coincided with other relevant studies [32,39]. While it is impractical to achieve emission reduction through limited development, as tourism is one of the pillar industries in China, the excessive rise of expenditure size should be curbed as it relates to tourism transport, accommodations, catering, and shopping that nets huge CO<sub>2</sub> emissions [52]. In view of this, with the process of urban integration in the YRD, local governments should further enhance their collaboration of low-carbon tourism for tourist arrivals. For example, optimization of the public transport system, promotion of high-speed railways network, and production of low-carbon tourist souvenirs. Meanwhile, a low-carbon consumption should be propagated and encouraged, as there is still a substantial gap between the positive perceptions of low-carbon knowledge held by tourists and residents, and the levels of practice in the YRD [52,90].

Second, energy intensity was the main contributor to reduce CO<sub>2</sub> emissions in the YRD, which was corroborated by the findings of Tang et al. [24] and Robaina-Alevis et al. [33]. We argue that the energy intensity reduction is the most promising and important factor for emission reduction. This assumption is due to the fact that there will be ample opportunities for energy efficiency improvement via clean energy, as well as low-carbon technology in the tourism sectors. However, the low-carbon technology is limited to tourism operators in the YRD due to high implementation costs. The cost issue is also evident for developed countries [91]. In addition, in 2016, although China passed the new Energy Conservation Law, there are no specific penalties for violations. Moreover, there are no other measures toward the technical standards and threshold of carbon emissions from enterprises. Therefore, energy law should be implemented with corresponding penalties at the legislative level, as well as the formulation of specific technical measures to ensure the improvement of energy efficiency in tourism. Moreover, strong support and greater reliance on clean and renewable energy (for example, hydropower, wind power, solar energy, biomass energy) in the tourism sector in the YRD is needed. Since the tourism transport sector emitted the most CO<sub>2</sub>, it is prudent to further emphasize the use of new-energy vehicles (for example, electric or plug-in hybrid) for green/sustainable transportation systems [6,68].

Third, the spatial structure effect contributed to the CO<sub>2</sub> reduction in the YRD mainly due to the change of the spatial distribution of tourism economic development. Nevertheless, reduction target of CO<sub>2</sub> emissions cannot depend on the further adjustment of the spatial structure through policies as tourism economy has grown in importance at each destination. With respect to the sectorial structure, although it had the weakest effect on CO<sub>2</sub> emissions reduction, it is still significant to further optimize the tourism sectorial structure for the long term. This would contribute to enhance the quality and level of regional tourism economic development, and lead to favorable carbon emissions reduction [86,92].

There are limitations to this study. First, due to the complexity of the tourism system and data availability, only the direct energy consumption and CO<sub>2</sub> emissions from tourism were estimated. Second, with respect to the three tourism sectors, transport data were limited to the main public transport, and accommodations limited to star-rated hotels. However, private/hired cars and homestay accommodation are also popular in the YRD, and were not considered due to the lack of attainable data. This likely leads to an underestimation of CO<sub>2</sub> emissions for tourism transport and accommodations.

Nevertheless, it is still important to implement strategies to reduce the level of tourism-induced energy consumption and CO<sub>2</sub> emissions due to the intra-regional imbalance, and complex decoupling relationship between the environment and the tourism industry in the YRD.

## 7. Conclusions

Based on the YRD as a case study, this research quantitatively examined the dynamics of regional tourism towards a low-carbon economy in terms of the relationship between tourism, CO<sub>2</sub> emissions, and economic development. The bottom-up approach, decoupling analysis, and LMDI decomposition method examined and integrated to explore the relationships. By means of the bottom-up approach, from 2001 to 2015, the amount of tourism-induced energy consumption and CO<sub>2</sub> emissions in the YRD increased. Tourism-related transport from Shanghai was the major contributor towards emissions. Decoupling analysis indicated that the decoupling state during 2001–2015 was deemed desirable in the YRD with respect to a low-carbon tourism economy, except in 2004. However, within the YRD, the decoupling situation was more complicated, especially in Shanghai. The separate effects of tourism on CO<sub>2</sub> emissions were explored by LMDI decomposition, which provided an in-depth examination of the relationship between tourism development and carbon emissions. In YRD, industry size and expenditure size effect were the principal factors to promote carbon emissions growth, whereas energy intensity, spatial structure, and sectorial structure had negative effects. This led to key issues that should be emphasized by policymakers with regards to the promotion of low-carbon tourism development, especially energy intensity reduction from tourism.

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