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Research on air pollution loss measurement of harmful substance emissions from tourism energy consumption in Jiangsu Province of China based on low carbon constraints

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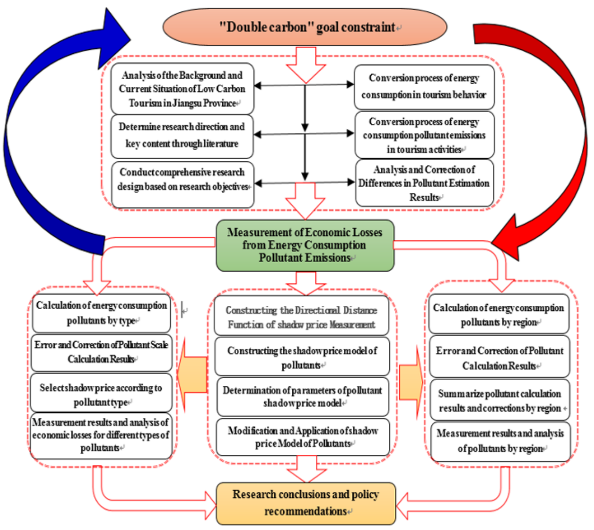
Graphical abstract



Abstract

In order to explore the air pollution loss measurement of energy consumption pollutant emissions in low-carbon tourism in Jiangsu Province, this paper, based on background analysis, literature review and research design, selects 13 prefecture-level cities in Jiangsu Province as research objects, and investigates the Measurement of Air pollution Losses from Energy Consumption Pollutant Emissions in 13 tourism areas in Jiangsu Province by reconstructing the shadow price model of air pollution loss and using the statistical data from 2013 to 2021 provided by the government. It is found that: the air pollution loss caused by the emission of eight pollutants of low-carbon tourism energy consumption in Jiangsu province ranges from 142.92 million yuan to 253.93 million yuan, and the air pollution loss of low-carbon tourism energy consumption emission in 13 prefecture-level cities is the largest in Nanjing, which produces an air pollution loss of 387.69 million yuan in 2019, and the lowest air pollution loss year is 2020, with an air pollution loss of 2430.02 million yuan. Therefore, to reduce the air pollution loss of 13 prefecture-level cities as well as 8 energy consumption pollutants in Jiangsu Province, special attention should be paid to the maximum index as well as the minimum index, and the economic loss caused by the energy consumption pollutant emission of low-carbon tourism in the province should be controlled by strategies such as minimizing the maximum air pollution loss index as well as maintaining the minimum air pollution loss index.

Keywords: Air pollution loss measurement, energy consumption pollutant emission, air pollution loss, shadow price model, Low carbon constraint.

1. Introduction

Jiangsu Province is not only a big economic province in China, but also a big tourism province. In 2021, both the number of tourists and the total tourism revenue reached a historic high, with 707 million domestic and foreign tourists and a total tourism revenue of 116.772 billion yuan, the proportion of tourism revenue to GDP exceeded 10%, reaching 10.03%, and the contribution of tourism value added to GDP exceeded 6% (Cao *et al.* 2023). With the rapid development of the tourism industry in Jiangsu Province, the increase of various activities such as transportation, accommodation, catering, entertainment, communication and postal services for tourists has gradually caused a certain degree of pollution in scenic spots, mainly in the form of air pollution, water pollution and soil pollution in scenic spots, which constantly cause environmental pollution in addition to the damage to the environment and the impact on the health of residents (Guo and Wang 2022). In order to strengthen the performance assessment of environmental pollution losses generated by green energy consumption carbon emissions in Jiangsu Province, in order to explore effective ways to minimize low-carbon green in Jiangsu Province, this paper attempts should take the carbon emissions generated by various tourism activities of tourists in Jiangsu Province as

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well as the scale of pollutant emissions, using the shadow price method to study the environmental pollution losses of various pollutant emissions from low-carbon tourism energy consumption in Jiangsu Province (Han *et al.* 2019). The shadow price model is mainly used to measure the shadow price of various pollutants emitted from tourism energy consumption, and then the environmental pollution losses caused by low-carbon tourism in Jiangsu Province are measured using the shadow price and the amount of pollutants counted (Han *et al.* 2020). With the rapid development of tourism in Jiangsu Province, the pollutant emission from tourism energy consumption has caused environmental pollution in Jiangsu Province to a large extent, which poses a certain threat to the living environment and health of residents in Jiangsu Province, and the side effects of tourism activities have gradually emerged. In order to strengthen the environmental pollution governance of ecotourism in Jiangsu Province, Jiangsu Province has taken a series of measures, and the state has also formulated a series of development strategies for the healthy development of low-carbon tourism (Han and Cao, 2022). The green transformation proposed by the 18th Party Congress in 2012, the ecological protection and high-quality development strategy of the Yellow River Basin in 2019, the "double carbon" target in 2020, and the Party's green transformation strategy of the "20th National Congress" and the requirements of the white paper "China's Green Development in the New Era" in 2023, low-carbon tourism has become an inevitable trend, and making full use of the green low-carbon transformation to completely solve the air pollution problems caused by China's economic development has gradually become an important strategic task (Chen and Mei., 2022). In this situation, it is of great practical significance as well as very urgent to study the air pollution loss of energy consumption and emission of low-carbon tourism in Jiangsu Province, and to improve the performance evaluation of low-carbon tourism in Jiangsu Province as well as the ecological compensation system.

Academic research on air pollution loss from low-carbon tourism energy consumption began in the mid-1980s; Zhou (1985) studied the measurement of air pollution loss; Huang (1986) studied the analysis of air pollution loss in Guilin tourism and explored specific measures to improve it in the context of Guilin tourism; Zhong *et al.* (2011) studied the impact of green on environment in China, where tourism has damaged the ecological environment to some extent and also caused a large air pollution loss; Can and Alp (2012) studied the conservation value generated by the protection of seascapes in Turkish tourism, which is a positive measure of tourism environmental value loss; Stylidis and Terzidou (2014) analyzed the relationship between the economic crisis and tourism development in Greek Kavala, arguing that the economic crisis has caused serious economic losses to tourism; Yu *et al.* (2016) analyzed the current situation of micro plastic pollution in Bohai Bay, China, arguing that micro plastics have caused serious air pollution and huge economic losses; Canteiro *et al.* (2018) analyzed the impact of tourism on air pollution in nature reserves in Uruguay, concluding that air pollution has caused huge environmental losses and that necessary restrictions on tourist behaviour should be strengthened; Han *et al.* (2019) analyzed the measurement of energy consumption air pollution losses in China, and investigated effective methods to reduce energy consumption air pollution losses based on the results of air pollution loss measurement; Robinson *et al.* (2019) analyzed the air pollution situation of the Turks and Caicos Islands in the UK and concluded that tourism has caused serious air pollution to the islands, the resulting air pollution losses are significant, and the management of island visitors should be strengthened to reduce air pollution losses; Robaina *et al.* (2020) analyzed the ecological impacts of tourism in five European countries, including: Austria, Cyprus, United Kingdom, Italy and Switzerland. concluded that tourism has caused air pollution, especially on the atmosphere; Hao *et al.* (2021) concluded that: haze pollution has had a significant impact on tourism in China, mainly on the study by Mejjad *et al.* (2022) concluded that tourism is an important source of income for the Mediterranean coast and that the increase in tourism in recent years has caused some pollution and also serious pollution losses; the study by Ekonomou and Halkos (2023) concluded that, according to the Environmental Kuznets Curve (EKC) hypothesis, as tourism grows, pollution gains tend to decrease, but the key is to be able to invest in pollution governance at a higher rate of tourism revenues.

Based on the above literature review, it is clear that there is still relatively little research literature on the loss of tourism environment and its air pollution loss measurement, mainly because there are great differences in the tourism air pollution situation in different countries around the world, and the measurement of tourism air pollution loss carries great uncertainties. Due to the diffusion, expansion and uncertainty of tourism air pollution loss, the results of measuring tourism air pollution loss by different methods have great differences, and different measurement methods also have great uncertainties under different conditions. Therefore, there are relatively few studies on the measurement of tourism air pollution loss in the academic field, and the methods of measurement also have great variability. According to the current state of research on the measurement of tourism air pollution loss in the academic community, there are generally uncertainties in the environmental conditions of the measurement, the simplicity of the air pollution loss measurement method, the lack of comprehensiveness of the indicators and variables of the measurement, and the lack of standardization in the application of the air pollution loss measurement method, which largely reduces the validity of the results of the measurement of tourism air pollution loss. Therefore, under such circumstances, it is of great practical significance to study the measurement methods of tourism air pollution losses and improve the tourism air pollution loss compensation system, in order to standardize the tourism air pollution loss measurement system, achieve the innovation of tourism air pollution loss measurement methods and promote the tourism environmental loss measurement system, as well as maximize the effectiveness of tourism low carbon air pollution loss measurement results, etc. It is of great practical importance to standardize the tourism environmental impact measurement system, achieve innovation in the tourism environmental impact measurement methods and promote the tourism environmental impact measurement system, as well as maximize the validity of the tourism low-carbon environmental impact measurement results.

2. Materials and methods

2.1 Study subjects and data cycle

The tourism industry in Jiangsu Province is growing rapidly and has become one of the top tourism provinces in China, with a total of 707 million domestic and foreign visitors and a total tourism revenue of RMB 116.772 billion in 2021. In order to study the measurement method of energy consumption pollutant emission air pollution loss of low-carbon tourism in Jiangsu Province and its application, this paper takes 13 prefecture-level cities under the jurisdiction of Jiangsu Province as the research object of low-carbon tourism air pollution loss, adopts selected indicators as well as the method of reconstructing shadow price model, by measuring the shadow price of energy consumption pollutant of tourism in Jiangsu Province, and using the statistical results of tourism pollution pollutants provided by the government to calculate its air pollution loss. As the Chinese government has only started to publish the China Ecological Environment Status Bulletin since 2012, considering the validity of the results of measuring the air pollution losses of low-carbon tourism, this paper selects the government statistics from 2013-2021, implements the measurement of air pollution losses of low-carbon tourism energy consumption pollutant emissions in Jiangsu Province using the statistical information provided by the government, and uses the specific measurement results to study the reduction of This paper uses the government statistics to measure the air pollution losses of low-carbon tourism in Jiangsu Province. In this paper, the basic data used to measure the air pollution losses of low-carbon tourism energy consumption and pollutant emissions in Jiangsu Province were obtained from the Statistical Bulletin on Cultural and Tourism Development, the Bulletin on Ecological and Environmental Conditions, the Energy Statistics Yearbook, and the Statistical Yearbook of both the national and Jiangsu governments. The original data from the above bulletins and yearbooks were mainly used in the study, and necessary corrections were made for individual statistical sources, taking into account the requirements of consistency and comparability.

2.2. Construction of an air pollution loss measurement model

Tourism behavior energy consumption undesirable output will produce pollution to the air, water and land in Jiangsu Province. To facilitate the study, this paper treats them all as air quality impacts, and the unit price of pollution losses for different pollutants can be calculated using a shadow price model, and then the air pollution losses from tourism energy consumption CO_2 and pollutant emissions can be accounted for using specific pollutant emissions (Han *et al.* 2018). This paper mainly relies on Dr. Han Xiuyan's practice of using shadow prices to determine the shadow prices of atmospheric pollutants: CO_2, SO_2, NO_x, CO, PM_{10}, $PM_{2.5}$, O_3 and Pb, which are used to measure the value of air pollution losses from carbon emissions from tourism behavior and pollutant emissions from energy consumption in Jiangsu Province. If there are N decision units denoted by and each DMU has K inputs, the input vector can be expressed as $x=\left(x_1,x_2,\cdots,x_n\right)\in R_n^+$, the desired output vector is expressed as : $y=\left(y_1,y_2,\cdots,y_n\right)\in R_n^+$, then the non-desired output vector is expressed as : $y=\left(y_1,y_2,\cdots,y_n\right)\in R_n^+$. The combination function of input and output variables in decision-making units is represented by P(x) (Chung *et al.* 1997), and the expression of the combination function is :

$$P\left(x\right)=\left\{\left(y,u\right):Input\left(x\right),Output\left(y,u\right)\right\},r\in R_k^+ \qquad (1)$$

The input variables selected in this paper are: tourism industry fixed asset input, tourism service personnel input, energy input, and environmental protection investment; the desired output is: total tourism revenue; and the undesired outputs are: eight pollutants such as CO_2, SO_2, NO_x, CO, PM_{10}, $PM_{2.5}$, O_3, and Pb, the above are all variables of the air pollution loss measurement system studied in this article. In order to effectively measure the air pollution loss caused by energy consumption of low-carbon tourism in Jiangsu Province, the principle of Shadow price of pollutants under environmental technology constraints was analyzed. The shadow price of pollutants is generally measured by the distance method, that is, the shadow price is the distance from the combination point of expected output and unexpected output to the combination number P(x). To illustrate the principle of shadow price measurement, the following curve of combination function P(x) is drawn in the space of desired output and non-desired output, and this combination function curve is an upper convex curve. In the decision system of low-carbon tourism behavior, energy consumption CO_2 and harmful substance emissions in Jiangsu Province, the desired output y is the total income of tourism industry, and the undesired outputs are: CO_2, SO_2, NO_x, CO, PM_{10}, $PM_{2.5}$, O_3 and Pb and other eight pollutants, P(x) is the combination function of desired output and undesired output. If (y, u) is an observation point in the region of the combination function $P(x)$, and (β_y, β_u) is an equidistant reduction point of (y, u), it indicates that the point still remains within the range of $P(x)$ after being reduced in a certain proportion. According to the shadow price theory, the shadow price is the combination that maximizes the desired output and minimizes the undesired output. This combination is the distance from the combination of desired output and undesired output (y, u) to the combination function $P(x)$ within $P(x)$. The concepts of input and output distance functions and the specific solution of the directional distance function were first introduced by Shephard in the early 1950s (Shephard, 1953), this method has gradually become an effective means to solve the Shadow price of pollutants, and has been accepted by most scholars. In order to illustrate the principle of the directional distance function and facilitate the use of the directional distance function to solve the shadow price of pollutants, and then use the calculated shadow price of pollutants and the statistical scale of pollutants to calculate the economic losses caused by pollutants, the distance function diagram from the combination point of expected and unexpected outputs of the decision-making unit to the combination function P (x) is shown in Figure 1.

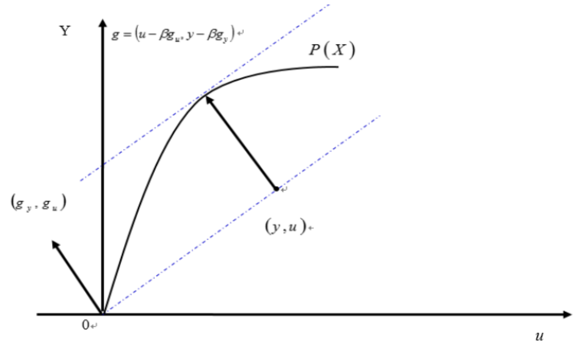

Figure 1. Schematic diagram of the principle of directional

From Figure (1), it can be seen that the distance point from the combination point of desired output and undesired output of the low-carbon tourism systesm in the value domain from *P*(*x*) to *P*(*x*) is the point parallel to the line formed by (*y*, *u*) and (β_y, β_u) tangent to *P*(*x*). In the above figure, (y,u)∈P(x), the direction vector of the output combination function can be expressed as: g = (g_y, g_u) and g ≠ 0; the direction vector of the desired output and undesired output combination point (y, u) is g = (y − βg_y, u − βg_u). If the directional distance function of the combination point (y, u) to the combination function *P*(*x*) is expressed by $\vec{D}_0\left(x,y,u;g_y,-g_u\right)$, then we have:

$$\vec{D}_0\left(x,y,u;g_y,-g_u\right)=\sup\left\{\begin{matrix}\beta:\left(\mathrm{y}+\beta g_y,u-\chi g_u\right)\\ \in P(x)\end{matrix}\right\} \tag{2}$$

In Eq. g_y is the desired output vector, g_u is the non-desired output vector, and β, χ is the coefficient of the directional distance function. According to the homogeneity property of Shephard's directional distance function, there is:

$$\vec{D}_0\left(x,y+\alpha g_y,u-\alpha g_u;g\right)=\vec{D}_0\left(x,y,u;g\right) \tag{3}$$

In the Eq. α is the coefficient of the vector equation, reflecting the multiple of expansion or contraction of the directional distance function, when the directional distance function of desired and non-desired outputs is g = (y, −u), the above directional distance function can be transformed into the following equation:

$$\vec{D}_0\left(x,y,u:y,-u\right)=\left(1/\vec{D}_0\left(x,y,-u\right)\right)-1 \tag{4}$$

According to the characteristics of the desired and undesired outputs in the low carbon tourism system and the chi-square nature of the directional distance function the following expression can be obtained: $\vec{D}_0\left(x,y,u;y,-u\right)=\sup\left\{\beta:D_0\left(x,y+\beta y,u+\beta u\right)\le 1\right\}$. Simplifying the above equation according to the theory of vector functions yields: $sup\left\{\beta:\left(1+\beta\right)\vec{D}\left(x,y,u\right)\le 1\right\}=sup\left\{\beta:1/\vec{D}\left(x,y,u\right)-1\right\}$. Taking g = (1, 1), the above equation is transformed into the following equation using the theory of Shephard's directional distance function:

$$\vec{D}_0\left(x,y,u\right)=\left[\lambda:\left(y\cdot\lambda^{-1},-u\cdot\lambda^{-1}\right)\right]-1 \tag{5}$$

In the Eq. λ is the coefficient of combination of desired output y and undesired output u, which reflects the multiple of expansion and contraction of desired output and undesired output. Since the above equation is the shortest distance from the output combination point (y, u) to the combination function *P*(x), it makes the desired output y reach the maximum while making the undesired output u reach the minimum. Therefore, this is the directional distance function of the output combination variable determined in this paper. If the price vector of input resources for the tourism industry in each prefecture-level city in Jiangsu Province is $p_x=\left(p_{x1},p_{x2},\cdots,p_{xn}\right)$, the corresponding expected output price vector is: $p_y=\left(p_{y1},p_{y2},\cdots,p_{yl}\right)$, and the corresponding unanticipated output price vector is: $p_u=\left(p_{u1},p_{u2},\cdots,p_{um}\right)$. If the profit function for the tourism industry in each city in Jiangsu Province is denoted by $\pi(p_r, p_y, p_u)$, then we have:

$$\pi\left(p_r,p_y,p_u\right)=\max_{x,y,u}\left\{yp_y-rp_r-up_u:\left(y,u\right)\in P\left(x\right)\right\} \tag{6}$$

As the energy consumption CO_2 and pollutant emission of tourism behavior in Jiangsu Province will pollute the environment, causing pollution of air, water and land, generating huge economic losses, and also damaging the ecological environment inhabited by human beings, causing great harm to plants and animals as well as human beings. Therefore, the economic loss generated by tourism energy consumption and emission should be deducted from tourism revenue or compensated by using investment in air pollution governance. Therefore, it is necessary to use the pollutant shadow price as well as the scale of pollutant emissions to determine the air pollution losses. According to Figure 3.7 it can be seen that (y, u)∈*P*(*x*) is also $\vec{D}_0\left(x,y,u;g_y,g_u\right)\ge 0$, according to which the above equation is simplified to the following equation:

$$\pi\left(p_x,p_y,p_u\right)=\max_{x,y,u}\left\{\begin{matrix}yp_y-rp_x-up_u:\vec{D}_0\\ \left(x,y,u;g_y,g_u\right)\ge 0\end{matrix}\right\} \tag{7}$$

If the output set (y, u) of tourism in each prefecture-level city in Jiangsu province is feasible under environmental technical conditions, then the corresponding directional vector(g_y, g_u) expanding or contracting by the coefficient of β is also feasible. Therefore, according to the vector distance function theory, the following equation should hold:

$$\left(y+\beta g_y,u-\beta g_u\right)=\left\{\begin{pmatrix}y+\vec{D}_0\left(x,y,u;g\right)\cdot g_y,\\ u-\vec{D}_0\left(x,y,u;g\right)\cdot g_u\end{pmatrix}\in P\left(x\right)\right\} \tag{8}$$

Comparing Equation (8) above with Equation (7), the result of Equation (8) can be used to correct Equation (7), and the corrected profit function can be expressed as:

$$\begin{aligned}\pi\left(p_x, p_y, p_u\right) \geq &\left(y p_y - r p_x - u p_u\right) \\ &+p_y \vec{D}_0(x, y, u; g) \cdot g_y \\ &+p_u \vec{D}_0(x, y, u; g) \cdot g_u\end{aligned} \tag{9}$$

The left side of the above inequality indicates the maximum profit achieved by the tourism industry in each prefecture-level city in Jiangsu province, while the right side of the inequality indicates the additional profit that can be obtained after the elimination of inefficiencies by the actual profit obtained by the tourism industry, and this additional profit depends on the difference obtained by equation (8), which is the directional distance function. However, when tourism reaches the maximum profit, it must find the shortest distance from the output point (y, u) to the combinatorial function P(x) .This shortest distance of the directional variable can be expressed as:

$$\begin{aligned}\vec{D}_0(x, y, u; g) \leq &\begin{bmatrix}\pi\left(p_x, p_y, p_u\right) \\ -\left(y p_y - x p_x - u p_u\right)\end{bmatrix} \\ &\cdot\left(g_y p_y + g_u p_u\right)^{-1}\end{aligned} \tag{10}$$

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Based on the results of the above analysis of the directional distance function, in order to achieve an effective measure of the shadow price of the non-desired output of tourism energy consumption, the above equation is transformed into the following expression using the method of extreme value solving:

$$\vec{D}_0(x, y, u; g) = \min\left\{\begin{bmatrix}\pi\left(p_x, p_y, p_u\right) - \\ \left(y p_y - r p_x - u p_u\right) \\ \cdot\left(g_y p_y + g_u p_u\right)^{-1}\end{bmatrix}\right\} \tag{11}$$

Based on the results of the above analysis of the directional distance function, in order to achieve an effective measure of the shadow price of the non-desired output of tourism energy consumption, the above equation is transformed into the following expression using the method of extreme value solving:

$$\begin{cases}\partial \vec{D}_0(x, y, u; g) / \partial y = 0 \Rightarrow -p_y \cdot\left(g_y p_y + g_u p_u\right)^{-1} = 0 \\ \partial \vec{D}_0(x, y, u; g) / \partial u = 0 \Rightarrow p_u \cdot\left(g_y p_y + g_u p_u\right)^{-1} = 0\end{cases} \tag{12}$$

In order to determine the shadow price of non-desired output items, solving this joint cubic equation system for the state above equal to zero, the shadow price model for non-desired output pollutants in tourism can be determined as follows:

$$\begin{aligned}p_u = -p_y \cdot &\left[\partial \vec{D}_0(x, y, u; g) / \partial u\right] \\ \cdot&\left[\partial \vec{D}_0(x, y, u; g) / \partial y\right]^{-1}\end{aligned} \tag{13}$$

When there are multiple desired and non-desired outputs in the tourism industry, the shadow price of the i_{th} desired output price is denoted by P_{yi} and the shadow price of the j-th non-desired output pollutant is denoted by P_{uj} . Using the extreme value method, it can be easily determined and the shadow price model for multiple output states is expressed as follows:

$$p_{uj} = -p_{yi} \frac{\gamma_j + \sum_{k=1}^{K} \beta_{tk} u_{tk} + \sum_{l=1}^{L} \eta_{tl} x_{tl} + \sum_{h=1}^{H} \mu_{th} u_{th}}{\beta_j + \sum_{k=1}^{K} \beta_{tk} y_{tk} + \sum_{l=1}^{L} \delta_{tl} x_{tl} + \sum_{h=1}^{H} \mu_{th} y_{th}} \tag{14}$$

The above equation is the shadow price model of pollutants emitted by energy consumption in tourism, and it is relatively easy to account for the shadow price of pollutants emitted by energy consumption in tourism behavior, provided that certain methods are used to achieve the estimation of the model parameters.

2.3. Estimation of parameters of a model for measuring the shadow price

In fact, since the shadow price model identified above is constructed using a directional distance function, there are parameters in the model that reflect the magnitude of the shadow price model without being able to directly use the shadow price model to determine the shadow price of non-desired output pollutants. To calculate the shadow price of energy emissions from low-carbon tourism, it is necessary to first estimate the parameters of the shadow price model. Because the parameters of the directional distance function and the parameters of the shadow price model are the same. Therefore, the parameters can be estimated by combining the two. According to the theory and method of distance function, parametric linear programming method and extreme value theory can be used for parameter estimation (Färe *et al.* 2007). In the low-carbon tourism decision system, the parameter estimation is carried out using the shadow price model of tourism energy consumption CO_2 and harmful substance emissions. First, the parametric programming model for parameter estimation is constructed based on the shadow price model determined above, with the following model expressions ：

$$f(x, y, u; g) = \min \sum_{t=1}^{T} \sum_{\mathrm{k}=1}^{K} \left\{\vec{D}_{0t}\left(x_{tk}, y_{tk}, u_{tk}; 1,1\right) - 0\right\} \tag{15}$$

$$S \cdot t \cdot \begin{cases}\vec{D}_0^t\left(x_{tk}, y_{tk}, u_{tk}; 1,1\right) \geq 0 \\ \partial \vec{D}_0^t\left(x_{tk}, y_{tk}, u_{tk}; 1,-1\right) \cdot\left(\partial y_{jk}^t\right)^{-1} \leq 0 \\ \beta - \sum_{j=1}^{J} \gamma_j = -1 \\ \beta' - \sum_{j=1}^{J} \mu_j = 0 \\ \delta_i - \sum_{j=1}^{J} \eta_{ij} = 0 \\ \sum_{j'=1}^{J} \gamma_{jj'} - \mu_j = 0 \\ \alpha_{ii'} = \alpha_{i'i} \\ \beta_{jj'} = \beta_{j'j} \\ \gamma_{nn'} = \gamma_{n'n} \\ i \neq i', j \neq j', n \neq n'\end{cases}$$

According to the theory of directional distance function, to estimate the parameters of shadow price model, the quadratic directional distance function is selected among numerous parameter estimation methods to determine the parameters of shadow price model. If the starting vector of the combination point of expected output and discarded expected output is determined as: g= (1, 1). The tourism industry in Jiangsu Province has K internal sectors, and in this paper, the internal sectors are chosen to be the tourism sectors of each prefecture-level city, then the quadratic directional distance function for each sector of k in period t within the fiscal year is expressed as follows ：

$$\partial\vec{D}_0\left(x_{it},y_{it},u_{it};1,1\right)=\alpha_0+\sum_{i=1}^{\mathrm{I}}\alpha_{\mathrm{i}}x_{it}+\sum_{j=1}^{J}\beta_j y_{jt}+\sum_{k=1}^{K}\gamma_k u_{kt}\frac{1}{2}$$
$$\sum_{i=1}^{\mathrm{I}}\sum_{i'=1}^{\mathrm{I}}\alpha_{ii'}x_{it}x_{i't}+\frac{1}{2}\sum_{\mathrm{j=1}}^{\mathrm{J}}\sum_{\mathrm{j'=1}}^{\mathrm{J}}\beta_{\mathrm{jj'}}y_{jt}y_{j't}+\frac{1}{2}$$
$$\sum_{\mathrm{k=1}}^{\mathrm{K}}\sum_{\mathrm{k'=1}}^{\mathrm{K}}\gamma_{\mathrm{kk'}}u_{kt}u_{k't}+\sum_{\mathrm{i=1}}^{\mathrm{I}}\sum_{\mathrm{j=1}}^{\mathrm{J}}\delta_{\mathrm{ij}}x_{jt}y_{jt}+$$
$$\sum_{\mathrm{i=1}}^{\mathrm{I}}\sum_{\mathrm{k=1}}^{\mathrm{K}}\eta_{\mathrm{ik}}x_{kt}u_{kt}+\sum_{\mathrm{j=1}}^{\mathrm{J}}\sum_{\mathrm{k=1}}^{\mathrm{K}}\mu_{\mathrm{jk}}y_{kt}u_{kt} \tag{16}$$

Where: r_{it} is the input resources of the i_{th}, period t. In this paper, we choose four input variables: fixed asset investment in tourism, tourism service personnel in each municipality, energy consumption in tourism behavior and investment in air pollution governance in tourism; y_{it} is the expected output of the i_{th}, period t. In this paper, we choose one expected output of total tourism revenue in each municipality; u_{it} is the non-expected output of the ith, period t. In this paper, we choose: CO_2, SO_2, NO_x, CO, PM_{10}, $PM_{2.5}$, O_3 and P_b. According to the chi-square nature of Shephard's directional distance function, the directional distance function is simplified based on the comprehensive analysis, and the specific simplified results are as follows ：

$$\vec{D}_0^t\left(x_{tn},y_{tn}+\alpha g_y,u_{tn}-\alpha g_u;1,-1\right)=$$
$$\vec{D}_0\left(x_{tn},y_{tn},u_{tn};1.-1\right)-\alpha \tag{17}$$

To calculate the shortest distance from the combination point of expected pass output and non-expected output to the combination function, it is necessary to determine the extreme value point of the combination function. Extreme value theory can be used to find the second-order partial derivatives of the relevant variables of the output combination function, and the relevant system of joint cubic equations can be established based on the results of solving the partial derivatives, and the parameters of the shadow price model can be determined by solving the system of equations. Then, using mathematical methods to perform partial derivative operations on the above system of equations, the results of the operations are simplified to obtain the following simplified system of equations ：

$$\begin{cases}\beta-\sum_{j=1}^{J}\gamma_j=-1\\ \beta'-\sum_{j=1}^{J}\mu_{ij}=0\\ \delta-\sum_{j=1}^{J}\eta_j=0\\ \sum_{j'=1}^{J}\gamma_{jj'}-\mu_j=0\end{cases} \tag{18}$$

The constraints of the parametric planning equation are imposed on the non-negative and monotonicity properties of the directional distance function, which allows for a negative shadow price of pollutants emitted by tourism energy consumption. Since $\partial\vec{D}_0\left(r_{it},y_{it},u_{it};1,1\right)=f\left(x,y,u;g\right)\geq 0$, and the corresponding $\partial\vec{D}_0^t\left(r_{tk},y_{tk},u_{tk};1,-1\right)\cdot\left(\partial y_{jn}^t\right)^{-1}=\beta+\beta' y_k+\sum_{i=1}^{I}\delta_i r_{ik}+\sum_{j=1}^{J}\mu_j u_{jk}\leq 0$ ， likewise have: $\partial\vec{D}_0^t\left(r_{tn},y_{tn},u_{tn};1,-1\right)\partial u_{kn}^t=\gamma_j+0.5\cdot\sum_{j'}^{J}\gamma_{jj'}u_{j'k}+\sum_{i=1}^{I}\eta_{ij}r_{ik}+\mu_j y_k\geq 0$. Therefore, based on these three constraints it is possible to characterize the directional distance function as a quadratic function using Chambers' method and to estimate the quadratic function to a second-order approximation. That is, the parameters of the directional distance function are determined by using the method of solving for the partial derivatives of the quadratic function, and the specific solution results are detailed in the following expressions ：

$$\frac{\partial\vec{D}_0\left(x_k,y_k,u_k;g_y,g_u\right)}{\partial x_{ik}}=\alpha_i;\frac{\partial\vec{D}_0\left(x_k,y_k,u_k;g_y,g_u\right)}{\partial y_k}=$$
$$\beta_j;\frac{\partial\vec{D}_0\left(x_k,y_k,u_k;g_y,g_u\right)}{\partial u_{jk}}=\gamma_j$$

$$\frac{\partial\vec{D}_0\left(x_k,y_k,u_k;g_y,g_u\right)}{\partial x_{ik}}=\alpha_i;\frac{\partial\vec{D}_0\left(x_k,y_k,u_k;g_y,g_u\right)}{\partial y_k}=$$
$$\beta_j;\frac{\partial\vec{D}_0\left(x_k,y_k,u_k;g_y,g_u\right)}{\partial u_{jk}}=\gamma_j$$

$$\frac{\partial\vec{D}_0\left(x_k,y_k,u_k;g_y,g_u\right)}{\partial x_{ik}\partial r_{i'k}}=\alpha_{ii'};$$
$$\frac{\partial\vec{D}_0^2\left(x_k,y_k,u_k;g_y,g_u\right)}{\partial y_k^2}=\beta_{jj'};$$
$$\frac{\partial\vec{D}_0\left(x_k,y_k,u_k;g_y,g_u\right)}{\partial u_{jk}\partial u_{j'k}}=\gamma_{jj'}$$

$$\frac{\partial\vec{D}_0\left(x_k,y_k,u_k;g_y,g_u\right)}{\partial x_{ik}\partial y_k}=\delta_i;$$
$$\frac{\partial\vec{D}_0\left(x_k,y_k,u_k;g_y,g_u\right)}{\partial x_{ik}\partial u_{jk}}=\eta_{ij};$$
$$\frac{\partial\vec{D}_0\left(x_k,y_k,u_k;g_y,g_u\right)}{\partial y_k\partial u_{jk}}=\mu_{ik}$$

Using the above set of equations, it is possible to achieve the estimation of the shadow price model of non-desired outputs of tourism energy consumption. By substituting the already estimated model parameters back into equation (14), it is easy to calculate the shadow price of non-desired outputs of tourism energy consumption and achieve the accounting of economic losses caused by the emissions of non-desired outputs of tourism energy consumption.

3. Results and discussion

3.1 Results of measuring the shadow price of pollutants

Jiangsu Province is a major economic province in China, as well as a major tourist province. The current status of non-expected pollutant emissions of tourism behavior energy consumption in Jiangsu province and 13 prefecture-level cities as well as the current status of air pollution management have been analyzed in detail above. In order to effectively measure the air pollution loss of non-expected output of tourism energy consumption in Jiangsu province, the relevant basic data have been revised in the process of determining the basic data. For example, for the issue of fixed asset investment in tourism in Jiangsu Province, for the development of attractions historical and cultural relics repasir and other acts of investment is relatively concentrated, most statistics of fixed asset investment does not take into account the value of classic assets, which makes the book value of tourism fixed asset investment shows too much fluctuation. To solve this problem this paper combines the smoothing of tourism fixed asset investment for the study year as well as the depreciation method of homogenization, which reduces the fluctuation of tourism fixed asset investment and facilitates the calculation of air pollution loss measures for the non-desired output of tourism energy consumption ; For the number of people in the tourism industry at the end of the period, there are more people actually performing services than this result, and this paper does not consider indirect tourism service workers, nor indirect government-related personnel, but mainly those directly involved in tourism services within the tourism industry; energy consumption is not an actual energy consumption statistic, but a discounted result of energy consumption of tourism behavior is used ; The volatility of the book value of the EPC investment is also significant, and this paper uses the actual EPC investment tourism revenue share for the calculation and correction of the absorption ; The scale of non-desired pollutant emissions uses the results of the accounting. The input-output base information of the measurement of air pollution loss of non-expected output of tourism energy consumption in Jiangsu Province determined on this basis is detailed in Table 1.

Table 1. Jiangsu Province Tourism 2013-2021 input-output base statistics

Indicators	2013	2014	2015	2016	2017	2018	2019	2020	2021
X_{1j}	6940	7864	8769	9954	11307	13077	13902	8136	11564
X_{2j}	3477	4066	4621	5207	6198	7244	7883	7652	7823
X_{3j}	435.61	445.31	448.93	452.36	454.51	485.32	516.52	401.36	478.62
X_{4j}	624.64	661.17	698.06	747.43	779.87	789.56	808.69	631.21	773.78
X_{5j}	112.43	127.00	141.97	161.35	182.83	211.06	223.68	162.34	214.21
X_{6j}	1437.23	1521.28	1517.27	1621.32	1682.17	1702.31	1732.19	1466.02	1780.39
X_{7j}	32.2747	33.0918	34.3173	35.9516	36.7686	38.8113	40.854	20.4268	36.8202
X_{8j}	12.9744	13.3691	13.9328	14.7042	15.1119	16.0679	16.8318	8.3137	14.9122
`X_{9j}	303.87	311.82	323.58	339.10	346.91	365.99	385.13	192.52	346.88
X_{10j}	25.8843	26.6058	27.6597	29.0848	29.8193	31.5924	33.1734	16.4844	29.6403
X_{11j}	16.2019	16.6783	17.3646	18.2994	18.7888	19.9490	20.9172	10.3564	18.5942
X_{12j}	17.7575	18.2137	18.8779	19.7374	20.1124	21.1910	22.2246	11.0713	19.8461
X_{13j}	0.2017	0.2055	0.2124	0.2218	0.2261	0.2379	0.2508	0.1248	0.2242

Source: Calculated based on statistical information from Jiangsu Province (provincial and municipal levels) Statistical Yearbook, Energy Statistical Yearbook, Environmental Status Bulletin and Tourism Statistical Bulletin; EP: air pollution.

In Table 1， X_{1j} is total tourism revenue(100 million yuan), X_{2j} is investment in tourism fixed assets, X_{3j} is number of people in the tourism industry at the end of the period (10000 people), X_{4j} is energy input (10000 tons of standard coal), X_{5j} is the investment in air pollution governance (100 million yuan), X_{6j} is CO_2 emission scale (10000 tons), X_{7j} is SO_2 emission scale (10000 tons), X_{8j} is NOx emission scale 10000 tons), X_{9j} is CO emission scale (10000 tons), $X1_{0j}$ is $PM_{2.5}$ emission scale (10000 tons), X_{11j} is PM_{10} emission scale (10000 tons), X_{12j} is O_3 emission scale (10000 tons), X_{13j} is Pb emission scale million (10000 tons). According to the shadow price model and the results of the analysis of the parameter determination method, the magnitude of the parameters of the directional distance function depends on the number and status of the input and output variables of the production decision system. In this paper, we choose: four input variables such as fixed assets, number of employees, energy consumption, and investment in air pollution governance; one desired output variable, total output value; and eight non-desired energy pollutant output variables, CO_2 emission scale, SO_2 emission scale, NO_2 emission scale, CO emission scale, PM_{10} emission scale, $PM_{2.5}$ emission scale O_3 emission scale, and Pb emission scale. According to the shadow price model estimation method for non-expected output pollutants, there are 139 parameters of variables that need to be estimated under this combination of tourism inputs and outputs. In order to reduce the workload of the shadow price model parameter estimation, this paper introduces some technical methods to simplify the parameter estimation according to the nature and structure of the equation, and the parameter estimation is calculated using Lngo18.0.44 software. It is a simple and powerful linear and nonlinear solver with a complete integrated installation package for building and editing fully functional environments for solving systems of nonlinear equations of all kinds, which makes complex calculations very easy. In this paper, based on the above constructed shadow price model parameter estimation equations (15) - (18), 139 model parameters are easily determined by inputting the underlying data into the input of Lngo18.0.44 software, on the basis of comparing the model parameters with the shadow price model (14) and the directional distance function (16). In addition to fully utilizing various specific conditions, parameter estimation in shadow price models also involves various specific methods, such as calculating or allocating individual parameter values during the process of determining specific parameters. Based on comprehensive analysis, use computers and specialized software to calculate and determine, and the specific shadow price model parameter estimation results are shown in Table 2.

Table 2 Estimation results of the parameters of the shadow price model for non-expected output pollutants

Parameters	Estimated value	Parameters	Estimated value	Parameters	Estimated value	Parameters	Estimated value	Parameters	Estimated value
α_0	-0.2136	γ_6	-0.1295	γ_{42}	-0.1851	γ_{76}	-0.1015	η_{26}	0..0975
α_1	0.1216	γ_7	-0.1214	γ_{43}	-0.1015	γ_{77}	-0.1192	η_{27}	0.1128
α_2	0.3126	γ_8	0.1124	γ_{44}	0.1523	γ_{78}	0.4217	η_{28}	-0.3482
α_3	0.1237	γ_{11}	0.4262	γ_{45}	0.0657	γ_{81}	0.3616	η_{31}	-0.6217
α_4	-0.2417	γ_{12}	0.2131	γ_{46}	0.1837	γ_{82}	-0.3224	η_{32}	0.0983
α_{11}	0.1643	γ_{13}	-0.1072	γ_{47}	0.1227	γ_{83}	0.2816	η_{33}	-0.2178
α_{12}	0.2021	γ_{14}	0.2857	γ_{48}	0.1675	γ_{84}	-0.0416	η_{34}	0.2073
α_{13}	0.1825	γ_{15}	-0.1636	γ_{51}	0.1889	γ_{85}	-0.0672	η_{35}	0.1827
α_{14}	-0.2162	γ_{16}	-0.2124	γ_{52}	0.2107	γ_{86}	0.0925	η_{36}	0.3016
α_{21}	0.0448	γ_{17}	0.2122	γ_{53}	0.2078	γ_{87}	0.1066	η_{37}	0.0923
α_{22}	0.1627	γ_{18}	0.3016	γ_{54}	0.1886	γ_{88}	0.0886	η_{38}	-0.8621
α_{23}	-0.2372	γ_{21}	0.2458	γ_{55}	0.0985	δ_{11}	-0.0768	η_{41}	0.0627
α_{24}	-0.3327	γ_{22}	0.2638	γ_{56}	0.0674	δ_{21}	0.0547	η_{42}	0.0875
α_{31}	0.2751	γ_{23}	-0.2236	γ_{57}	-0.0768	δ_{31}	0.0268	η_{43}	0.1027
α_{32}	0.3016	γ_{24}	-0.1827	γ_{58}	-0.0786	δ_{41}	0.1027	η_{44}	-0.7891
α_{33}	0.0981	γ_{25}	0.2151	γ_{61}	0.0864	η_{11}	-0.1926	η_{45}	0.0527
α_{34}	-0.2138	γ_{26}	0.1625	γ_{62}	0.0579	η_{12}	0.0279	η_{46}	0.0602
α_{41}	-0.1826	γ_{27}	0.2016	γ_{63}	0.0874	η_{13}	0.0653	η_{47}	-0.1295
α_{42}	0.2136	γ_{28}	0.3127	γ_{64}	0.1092	η_{14}	-0.0753	η_{48}	-0.1214
α_{43}	0.1627	γ_{31}	0.1627	γ_{65}	0.1627	η_{15}	0.1627	μ_{11}	0.1124
α_{44}	-0.2372	γ_{32}	-0.2372	γ_{66}	-0.2372	η_{16}	-0.2372	μ_{12}	0.4262
β_1	-0.3327	γ_{33}	-0.3327	γ_{67}	-0.3327	η_{17}	-0.3327	μ_{13}	0.2131
β_{11}	0.2751	γ_{34}	0.2751	γ_{68}	0.2751	η_{18}	0.2751	μ_{14}	-0.1072
γ_1	0.3016	γ_{35}	0.3016	γ_{71}	0.3016	η_{21}	0.3016	μ_{15}	0.2857
γ_2	0.0981	γ_{36}	0.0981	γ_{72}	0.0981	η_{22}	0.0981	μ_{16}	-0.1636
γ_3	-0.2138	γ_{37}	-0.2138	γ_{73}	-0.2138	η_{23}	-0.2138	μ_{17}	-0.2124
γ_4	-0.1826	γ_{38}	-0.1826	γ_{74}	-0.1826	η_{24}	-0.1826	μ_{18}	0.2122
γ_5	0.2136	γ_{41}	0.2136	γ_{75}	0.2136	η_{25}	0.2136		

Table 3 Results of shadow price calculation for pollutants of non-expected output of tourism energy consumption

No. (year)	CO_2	SO_2	NOx	CO	$PM_{2.5}$	PM_{10}	O_3	Pb
2013	-26.70	-2096	-1671	-54.32	-1351	-1146	-74.27	-10221
2014	-26.73	-2004	-1674	-54.89	-1362	-1169	-74.29	-10232
2015	-26.75	-2008	-1678	-55.06	-1366	-1173	-74.32	-10238
2016	-26.76	-2012	-1682	-55.13	-1369	-1176	-74.35	-10242
2017	-26.76	-2021	-1685	-55.14	-1372	-1178	-74.38	-10246
2018	-26.78	-2028	-1688	-55.41	-1375	-1182	-74.42	-10249
2019	-26.79	-2032	-1691	-55.44	-1377	-1185	-74.45	-10252
2020	-26.80	-2041	-1695	-55.45	-1381	-1188	-74.48	-10255
2021	-26.82	-2049	-1697	-55.45	-1384	-1192	-74.52	-10258

In the international process of model parameters, because there are some differences between the shadow price model constructed in this paper and the requirements of the directional distance function and Lngo18.0.44 software, the parameter estimation process is estimated separately for the non-conforming elements, making it impossible for the determined model parameters to fully conform to the actual situation. After the analysis of the estimated parameters and the trial operation of the model, it is verified that the estimated parameters basically meet the requirements of the shadow price model and the validity of the shadow price model is confirmed. In order to effectively calculate the shadow price of non-expected output pollutants of tourism energy consumption in Jiangsu Province, the above parameter estimation results are substituted into (16) quadratic directional distance function to determine the shortest distance, and then use formula (14) to calculate the shadow price of eight pollutants generated by tourism behavior energy consumption as detailed in Table 3.

The above is the result of the calculation of the shadow price of non-expected output harmful to tourism energy consumption in Jiangsu Province, the unit of measurement is yuan, in order to reduce the error, the individual results of the calculation of the coefficient correction.

3.2. Measurement results of air pollution loss of pollutants

On the basis of the calculation of the shadow price of pollutants for non-expected output of energy consumption in tourism behavior, the air pollution loss of non-expected pollutant emissions from tourism in Jiangsu Province can be easily calculated by multiplying the shadow price of pollutants with the results of pollutant emission scale accounting. The specific calculation results are detailed in Table 4.

Table 4 Calculation results of air pollution losses of non-expected output pollutants from tourism energy consumption

Indicator	2013	2014	2015	2016	2017	2018	2019	2020	2021
CO_2	-38372	-40657	-40589	-43384	-45018	-45585	-46411	-39293	-47753
SO_2	-67648	-66316	-68909	-72335	-74309	-78709	-83015	-41691	-75445
NOx	-21680	-22380	-23379	-24732	-25464	-27123	-28463	-14092	-25306
CO	-16505	-17116	-17817	-18695	-19128	-20280	-21353	-10675	-19235
$PM_{2.5}$	-3497	-3624	-3778	-3982	-4091	-4344	-4568	-2277	-4102
PM_{10}	-1857	-1950	-2037	-2152	-2213	-2358	-2479	-1230	-2216
O_3	-1319	-1353	-1403	-1467	-1496	-1577	-1655	-825	-1479
Pb	-2062	-2103	-2175	-2272	-2317	-2438	-2571	-1280	-2300
Total	-152940	-155499	-160087	-169019	-174036	-182414	-190515	-111363	-177836

Unit: Ten thousand yuan

Table 5 Calculation table of air pollution loss of non-expected output of tourism energy consumption

City Name	2013	2014	2015	2016	2017	2018	2019	2020	2021
Suzhou	-25740	-25645	-25830	-26575	-28393	-27301	-27662	-19307	-26479
Nanjing	-28529	-27306	-27412	-28178	-27987	-28783	-29086	-18936	-27562
Wuxi	-20754	-20621	-20790	-21410	-21325	-21996	-22264	-13384	-21514
Changzhou	-13638	-13583	-14069	-14937	-15295	-16187	-17284	-11458	-17109
Yangzhou	-11766	-12377	-12994	-14019	-14630	-15765	-16831	-8551	-14815
Zhenjiang	-11570	-11952	-12415	-13336	-13874	-14667	-15487	-8402	-13603
Xuzhou	-9161	-9720	-10352	-11259	-11531	-12900	-13782	-6135	-12703
Nantong	-5175	-6063	-6938	-7511	-7667	-8515	-9108	-5707	-8814
Lianyungang	-5205	-5486	-5857	-6419	-6814	-7453	-8055	-5356	-6522
Huai'an	-5439	-5690	-6007	-6511	-6817	-7371	-7956	-4908	-8051
Yancheng	-8122	-8347	-8753	-9456	-9823	-10680	-11420	-3612	-10550
Taizhou	-4867	-5034	-5266	-5690	-5943	-6425	-6866	-2821	-5711
Suqian	-2973	-3673	-3404	-3718	-3938	-4371	-4715	-2786	-4403
Total	-152941	-155499	-160088	-169017	-174037	-182413	-190517	-111364	-177836

Unit: Ten thousand yuan

From the above table, it is obvious that the economic loss generated by the non-expected pollutant emission of tourism energy consumption in Jiangsu Province in 2021 is as high as 2.34704 billion yuan, accounting for 0.2030% of the total tourism revenue of the same caliber in that year. As this paper only studied the economic loss generated by the domestic tourists' tourism behavior energy consumption non-expected pollutant emissions, considering that there are still some tourism energy consumption pollutants not considered, using a correction factor of 1.06, if in consideration on about 8% of foreign tourists, then there are: 2.34704 (1 + 0.06 + 0.08) = 2.67563 billion yuan.

3.3. Measurements of air pollution losses in prefecture-level cities in Jiangsu Province

The air pollution loss caused by non-expected harmful substances of tourism energy consumption in each prefecture-level city in Jiangsu Province can be accounted for using the same method as above city by city, or a simple method can be used to apportion the number of tourists or the percentage of total tourism income in each prefecture-level city, and the results of apportionment using the percentage of tourists in each prefecture-level city in this paper are detailed in Table 5.

The above results of air pollution loss apportioned using the number of tourists as a percentage may have some errors with the actual results, but this does not affect the results of the evaluation of the air pollution governance effect of carbon emissions from tourism energy consumption in each city later in this paper, and the revised air pollution loss accounting results are used in the evaluation.

3.4. Discussion of factors influencing air pollution loss in low carbon tourism

In this paper, the air pollution loss measurement of low carbon tourism energy consumption pollutant emissions in Jiangsu province is measured from two aspects: the type of pollutants in the province and by prefecture-level cities. From the analysis of the measurement results of air pollution loss of energy consumption pollutants of tourism, the curve family is drawn in the right-angle coordinate system using the measurement results in Table 3, which can obviously show the composition and changes of air pollution loss generated by different pollutants of low-carbon tourism in Jiangsu province, and the specific situation is shown in Figure 2.

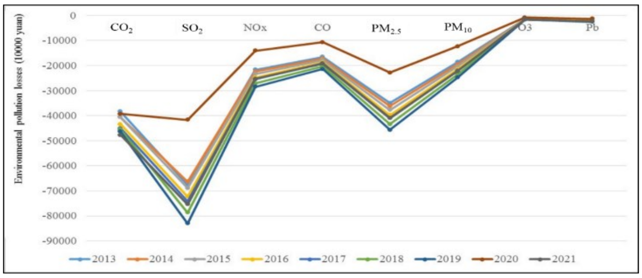

Figure 2. The composition and change of economic loss of tourism energy consumption pollutants

From the above graph can be clearly low to see that the air pollution loss of various pollutants of low-carbon tourism energy consumption in Jiangsu Province, the highest in 2019 and the lowest in 2020, which is mainly influenced by the epidemic ; In terms of the air pollution loss of different pollutants, the air pollution loss of O_3 and Pb is the smallest, and the air pollution loss of SO_2 is the largest. The air pollution losses of other pollutants are, in order: PM_{10}, CO, NO_x, $PM_{2.5}$ and CO_2.SO_2, CO_2 and $PM_{2.5}$ are the main pollutants in ambient air that affect the environment and the health of residents. Using the same method, the results of air pollution loss measurement for each year in each prefecture-level city in Jiangsu province are plotted in a right-angle coordinate system as a family of curves, and the specific status is shown in Figure 3.

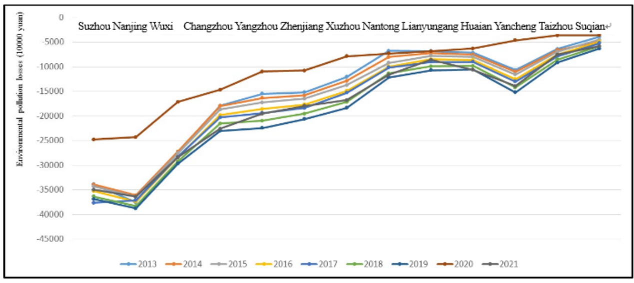

Figure 3. Change in air pollution losses of pollutants by prefecture-level cities

It can be clearly seen from Figure 3 that the air pollution losses of different prefecture-level cities in Jiangsu Province in terms of energy consumption pollutant emissions from tourism are the lowest in Suqian and the highest in Nanjing, and the air pollution losses of other prefecture-level cities are in the following order: Taizhou, Huai'an, Lianyungang, Nantong, Xuzhou, Yancheng, Zhenjiang, Yangzhou, Changzhou, Wuxi and Suzhou; From the annual changes, the tourism energy consumption air pollution loss of each prefecture-level city is the highest in 2019 and the lowest in 2020. Therefore, managers should develop corresponding strategies according to the change pattern of the above two measurement results to promote the sustainable reduction of economic loss of low-carbon tourism energy consumption and pollutant emission in Jiangsu Province.

4. Conclusions and recommendations

In order to explore the air pollution loss measurement method of low-carbon tourism energy consumption and pollutant emissions in Jiangsu Province, this paper selects the air pollution loss measurement of low-carbon tourism energy consumption and pollutant emissions in 13 prefecture-level cities in Jiangsu Province based on the research background analysis, literature review and research design. By reconstructing the shadow price model of air pollution loss of pollutants, the air pollution loss measurement of energy consumption pollutant emissions in 13 tourist areas in Jiangsu province was studied by using the basic information provided by the government. The study found that: the air pollution loss caused by the emission of eight pollutants from low-carbon tourism energy consumption in Jiangsu Province ranged from 142.92 million yuan to 253.93 million yuan, and the air pollution loss of low-carbon tourism energy consumption and emission in 13 prefecture-level cities was the largest in Nanjing, which produced an air pollution loss of 387.69 million yuan in 2019, and the lowest air pollution loss year was 2020, with an air pollution loss of 2430.02 million yuan. Therefore, to reduce the air pollution loss of 13 prefecture-level cities in Jiangsu Province as well as 8 energy consumption pollutants, special attention should be paid to the maximum indicators as well as the minimum indicators, and the economic loss generated from the emission of energy consumption pollutants in low-carbon tourism in the province should be governance led through strategies such as minimizing the maximum air pollution loss indicators as well as maintaining the minimum air pollution loss indicators. Based on the empirical test results of low-carbon tourism ecological efficiency indicators and driving factors in 13 prefecture level cities in Jiangsu Province, this article proposes policy recommendations to improve low-carbon tourism ecological efficiency in Jiangsu Province as follows:

(1)The loss of air pollution is planned to be controlled while maintaining tourism revenue in Nanjing. Air pollution losses are generally positively correlated with total tourism revenue, and reducing air pollution losses will inevitably lead to a decrease in total tourism revenue. From the perspective of efficient development of low-carbon tourism, air pollution losses from energy consumption and pollutant emissions should be promoted through the use of clean energy while maintaining total tourism revenue.

(2)Minimize the air pollution loss of SO_2 and CO_2. From the perspective of air pollution losses from energy consumption pollutant emissions, Jiangsu Province, the largest air pollution losses from SO_2 and CO_2, which is mainly caused by the consumption of petrochemical energy, the main means of control is to save emissions and the use of clean energy, in these means to gradually achieve green transformation is the key to the problem.

(3)Use a variety of means to control and reduce energy consumption pollutants air pollution losses. Reduce energy consumption pollutant emissions of air pollution losses, the key is to reduce or avoid energy consumption. At present, China's clean energy is not enough, green transformation is difficult to achieve at present, only through the adjustment of energy structure, planned to increase clean energy and maximum energy saving and emission reduction means to gradually achieve green transformation.

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References

Can Ö. and Alp E. (2012). Valuation of environmental improvements in a specially protected marine area: A choice experiment approach in Göcek Bay, Turkey. *Science of The Total Environment*, **43**: 291–298.

Canteiro M., Córdova-Tapia F. and Brazeiro A. (2018). Tourism impact assessment: A tool to evaluate the environmental impacts of touristic activities in Natural Protected Areas, *Tourism Management Perspectives*, **28**, 220–227.

Chen W.J. and Mei F.Q. (2022). Green Transformation Efficiency of Industries in China's Resource-Based Cities: Its Spatiotemporal Evolution and Driving Factors, *Ecological Economy*, **38**(11), 78–87.

Cao T.Y., Shen Q.Q. and Han X.Y. (2023). Study on measurement and drivers of low‑carbon tourism eco‑efficiency: evidence from Jiangsu Province, Environmental Science and Pollution Research, Published: 02, https://doi.org/10.1007/s11356-023-27294-6

Ekonomou G. and Halkos G. (2023). Is tourism growth a power of environmental 'de -degradation' An empirical analysis for Eurozone economic space, *Economic Analysis and Policy*, **77**, 1016–1029.

Färe R., Grosskopf S. and Pasurka Jr C.A. (2007). Environmental production functions and environmental directional distance functions, *Energy*, **32**(7), 1055-1066.

Guo Q, Wang Q.N. (2022). Double carbon goal and tourism value co-creation, *Tourism Tribune*, **37**(5), 3–5. https:// doi.org/10. 19765/j. cnki.1002- 5006. 2022. 05. 002

Han X.Y., Zhao T.Y. and Sun. T. (2018). Research on Environmental Responsibility Measurement of Energy Consumption Pollution from the Perspective of Virtual Value, *Research on the Generalized Virtual Economy*, **9**(4), 59–66.

Han X.Y., Sun T. and Feng Q. (2019). Study on environmental pollution loss measurement model of energy consumption emits and its application in industrial parks, *Science of The Total Environment*, **668**, 1259–1266.

Han X.Y., Sun T. and Cao T.Y. (2020). Study on environmental pollution loss measurement method of waste gas emits in Nanjing MV Industrial Park, *Environmental Science and Pollution Research*, **27**, 16539–16553.

Han X.Y. and Cao T.Y. (2022). Studyon the evaluation of ecological compensation effect for environmental pollution loss from energy consumption: Taking Nanjing MV Industrial Park as an example, *Environmental Technology & Innovation*, **27**, 102473.

Hao Y., Niu X.S. and Wang J.Z. (2021). Impacts of haze pollution on China's tourism industry: A system of economic loss analysis, *Journal of Environmental Management*, **295**, 113051.

Huang S.Q. (1986). Analysis of the economic loss of tourism environmental pollution and suggestions for countermeasures, *Environmental Protection*, **(7)**, 31–32.

Mejjad N., Rossi A. and Pavel A.B. (2022). The coastal tourism industry in the Mediterranean: A critical review of the socio-economic and environmental pressures & impacts, *Tourism Management Perspectives*, **44**, 101007.

Robinson D., Newman S.P. and Stead S.M. (2019). Community perceptions link environmental decline to reduced support for tourism development in small island states: A case study in the Turks and Caicos Islands, *Marine Policy*, **108**, 103671.

Robaina M., Madaleno M., Silva S., Eusébio C., Carneiro M.J., Gama C., Oliveira K., Russo M.A. and Monteiro A. (2020). The relationship between tourism and air quality in five European countries, *Economic Analysis and Policy*, **67**, 261–272.

Shephard R.W. (1953). Cost and production functions. Princeton University Press, *Princeton*.

Stylidis D. and Terzidou M. (2014). Tourism and the economic crisis in Kavala, Greece. *Annals of Tourism Research*, **44**, 210–226.

Yu X.B., Peng J.P., Wang J.D., Wang K. and Bao S. (2016). Occurrence of micro plastics in the beach sand of the Chinese inner sea: The Bohai Sea, *Environmental Pollution*, **214**, 722–730.

Zhou F.X. (1985). Discussion on the measurement method of economic loss of environmental pollution, *China Environment Management*, **(3)**, 14–16+22.

Zhong L.S., Deng J.Y., Song Z.W. and Ding P.Y. (2011). Research on environmental impacts of tourism in China: Progress and prospect, *Journal of Environmental Management*, **92**(11), 2972–2983.