# 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**
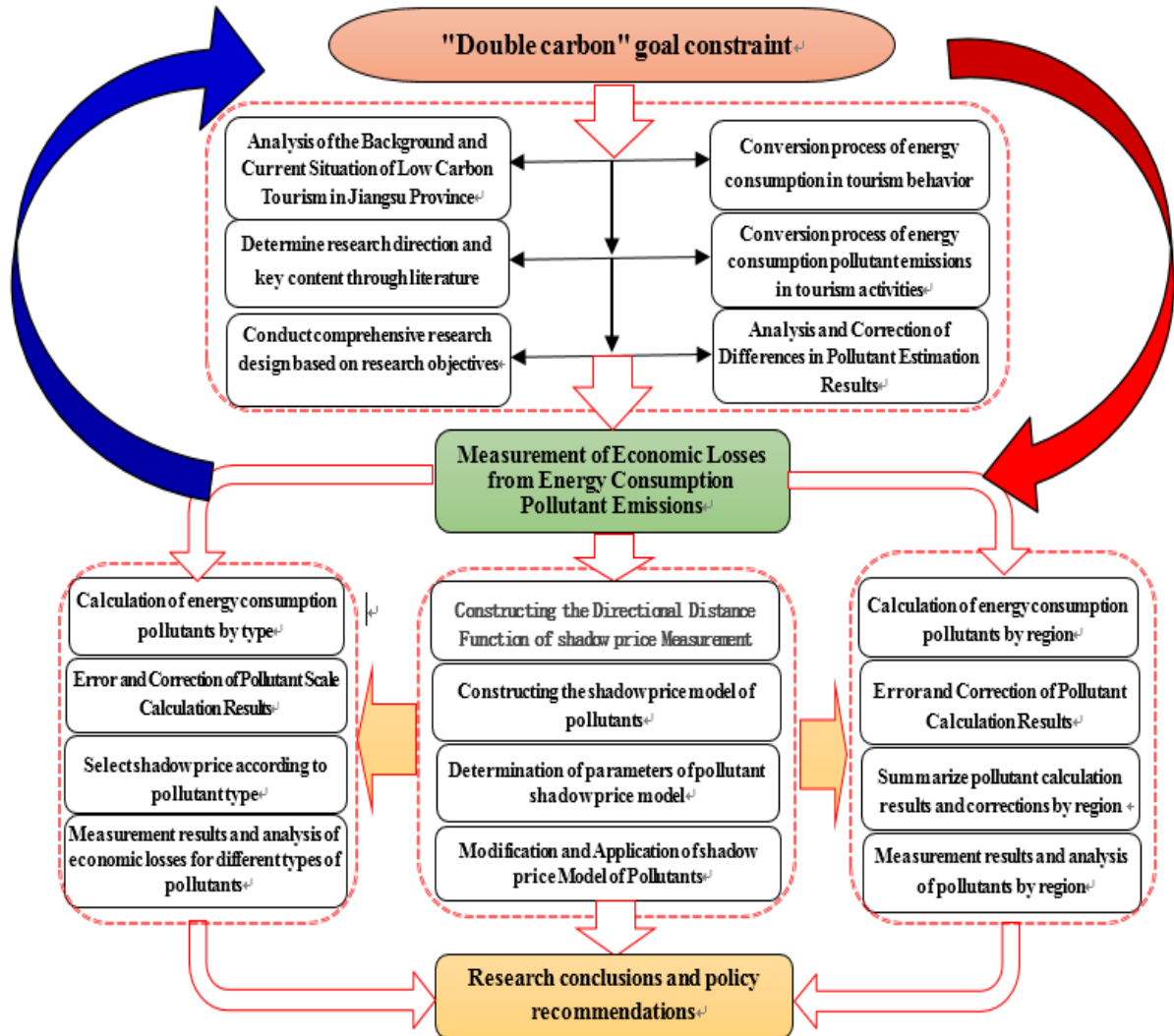
**Abstract:** In order to explore the air pollution loss measurement of energy consumption pollutant emissions in low-carbon tourism in Jiangsu Province, this paper, based on background analysis, literature review and research design, selects 13 prefecture-level cities in Jiangsu Province as research 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 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: $x = (x_1, x_2, \cdots, x_k) \in R_k^+$, the desired

output vector is expressed as: $y = (y_1, y_2, \cdots, y_n) \in R_n^+$, then the non-desired output vector is

expressed as: $u = (u_1, u_2, \cdots, u_m) \in R_m^+$. 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:

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

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

158  this article. In order to effectively measure the air pollution loss caused by energy consumption of

159  low-carbon tourism in Jiangsu Province, the principle of Shadow price of pollutants under

160  environmental technology constraints was analyzed. The shadow price of pollutants is generally

161  measured by the distance method, that is, the shadow price is the distance from the combination point

162  of expected output and unexpected output to the combination number P(x). To illustrate the principle

163  of shadow price measurement, the following curve of combination function P(x) is drawn in the space

164  of desired output and non-desired output, and this combination function curve is an upper convex

165  curve. In the decision system of low-carbon tourism behavior, energy consumption $CO_2$ and harmful

166  substance emissions in Jiangsu Province, the desired output y is the total income of tourism industry,

167  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,

168  P(x) is the combination function of desired output and undesired output. If $(y, u)$ is an observation

169  point in the region of the combination function $P(x)$, and $(\beta_y, \beta_u)$ is an equidistant reduction point

170  of $(y, u)$, it indicates that the point still remains within the range of $P(x)$ after being reduced in a

171  certain proportion. According to the shadow price theory, the shadow price is the combination that

172  maximizes the desired output and minimizes the undesired output. This combination is the distance

173  from the combination of desired output and undesired output $(y, u)$ to the combination function

174  $P(x)$ within $P(x)$. The concepts of input and output distance functions and the specific solution of

175  the directional distance function were first introduced by Shephard in the early 1950s (Shephard,

176  1953), this method has gradually become an effective means to solve the Shadow price of pollutants,

177  and has been accepted by most scholars. In order to illustrate the principle of the directional distance

178  function and facilitate the use of the directional distance function to solve the shadow price of

179  pollutants, and then use the calculated shadow price of pollutants and the statistical scale of pollutants

180  to calculate the economic losses caused by pollutants, the distance function diagram from the

181  combination point of expected and unexpected outputs of the decision-making unit to the combination

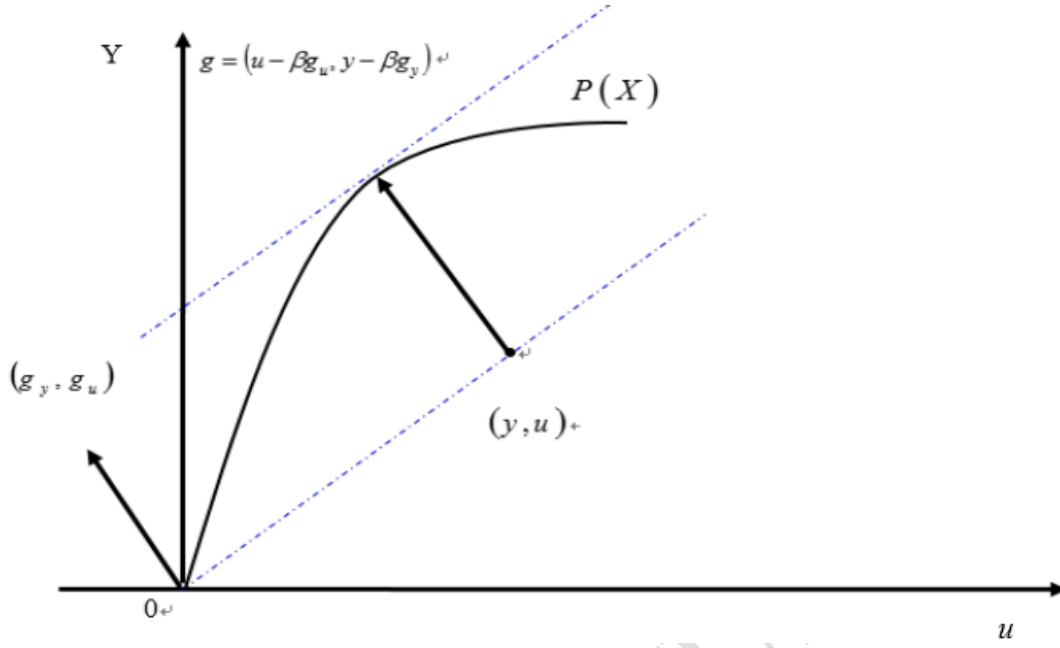182    function P (x) is shown in Figure 1.

183

184    **Fig.1.** Schematic diagram of the principle of directional

185    From Figure (1), it can be seen that the distance point from the combination point of desired

186    output and undesired output of the low-carbon tourism system in the value domain from $P(x)$ to

187    $P(x)$ is the point parallel to the line formed by （y，u） and $(\beta_y, \beta_u)$ tangent to$P(x)$. In the

188    above figure, （y，u）$\in$ P （x）, the direction vector of the output combination function can be

189    expressed as: $g = (g_y, g_u)$ and $g \neq 0$; the direction vector of the desired output and undesired

190    output combination point （y，u） is $g = (y\text{-}\beta g_y, u\text{-}\beta g_u)$. If the directional distance function of

191    the combination point （y，u） to the combination function $P(x)$ is expressed by

192    $\vec{D}_0\left(x, y, u; g_y, -g_u\right)$, then we have:

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

194    In Eq. $g_y$ is the desired output vector, $g_u$ is the non-desired output vector, and $\beta$，$\chi$ is the

195    coefficient of the directional distance function. According to the homogeneity property of Shephard's

196    directional distance function, there is:

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

9

198    In the Eq. $\alpha$ is the coefficient of the vector equation, reflecting the multiple of expansion or

199    contraction of the directional distance function, when the directional distance function of desired and

200    non-desired outputs is $g = (y, -u)$, the above directional distance function can be transformed into

201    the following equation:

202
$$\vec{D}_0\left(x, y, u : y, -u\right) = \left(1 \big/ \vec{D}_0\left(x, y, -u\right)\right) - 1 \qquad (4)$$

203    According to the characteristics of the desired and undesired outputs in the low carbon tourism

204    system and the chi-square nature of the directional distance function the following expression can be

205    obtained: $\vec{D}_0(x, y, u; y, -u) = \sup\{\beta: \ D_0(x, y + \beta y, u + \beta u) \le 1\}$. Simplifying the above equation according

206    to the theory of vector functions yields: $sup\{\beta : (1 + \beta)\vec{D}(x, y, u) \le 1\} = \ sup\{\beta : 1 \big/ \vec{D}(x, y, u) - 1\}$.

207    Taking $g = (1, 1)$, the above equation is transformed into the following equation using the theory of

208    Shephard's directional distance function:

209
$$\vec{D}_0\left(x, y, u\right) = \left[\lambda : \left(y \cdot \lambda^{-1}, -u \cdot \lambda^{-1}\right)\right] - 1 \qquad (5)$$

210    In the Eq. $\lambda$ is the coefficient of combination of desired output y and undesired output u, which

211    reflects the multiple of expansion and contraction of desired output and undesired output. Since the

212    above equation is the shortest distance from the output combination point （y，u） to the

213    combination function $P(x)$, it makes the desired output y reach the maximum while making the

214    undesired output u reach the minimum. Therefore, this is the directional distance function of the

215    output combination variable determined in this paper. If the price vector of input resources for the

216    tourism industry in each prefecture-level city in Jiangsu Province is $p_x = \left(p_{x1}, p_{x2}, \cdots, p_{xn}\right)$, the

217    corresponding expected output price vector is: $p_y = \left(p_{y1}, p_{y2}, \cdots, p_{yl}\right)$, and the corresponding

218    unanticipated output price vector is: $p_u = \left(p_{u1}, p_{u2}, \cdots, p_{um}\right)$. If the profit function for the tourism industry

219    in each city in Jiangsu Province is denoted by $\pi\left(p_r, p_y, p_u\right)$, then we have:

220
$$\pi\left(p_r, p_y, p_u\right) = \max_{x, y, u}\left\{yp_y - rp_r - up_u : (y, u) \in P(x)\right\} \qquad (6)$$

221    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 $(y, u) \in P(x)$ is also $\vec{D}_0(x, y, u; g_y, g_u) \geq 0$ , according to which the above

equation is simplified to the following equation:

$$\pi\left(p_x, p_y, p_u\right) = \max_{x,y,u} \left\{ y p_y - r p_x - u p_u : \vec{D}_0\left(x, y, u; g_y, g_u\right) \geq 0 \right\} \tag{7}$$

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 $\beta$ is also feasible. Therefore, according to the vector

distance function theory, the following equation should hold:

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

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:

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

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:

246 $$\vec{D}_0\left(x,y,u;g\right)\le\left[\pi\left(p_x,p_y,p_u\right)-\left(yp_y-xp_x-up_u\right)\right]\cdot\left(g_yp_y+g_up_u\right)^{-1}\qquad(10)$$

247 Based on the results of the above analysis of the directional distance function, in order to achieve

248 an effective measure of the shadow price of the non-desired output of tourism energy consumption,

249 the above equation is transformed into the following expression using the method of extreme value

250 solving:

251 $$\vec{D}_0\left(x,y,u;g\right)=\min\left\{\left[\pi\left(p_x,p_y,p_u\right)-\left(yp_y-rp_x-up_u\right)\cdot\left(g_yp_y+g_up_u\right)^{-1}\right]\right\}\qquad(11)$$

252 Based on the results of the above analysis of the directional distance function, in order to achieve

253 an effective measure of the shadow price of the non-desired output of tourism energy consumption,

254 the above equation is transformed into the following expression using the method of extreme value

255 solving:

256 $$\begin{cases}\partial\vec{D}_0\left(x,y,u;g\right)\big/\partial y=0\Rightarrow-p_y\cdot\left(g_yp_y+g_up_u\right)^{-1}=0\\\partial\vec{D}_0\left(x,y,u;g\right)\big/\partial u=0\Rightarrow p_u\cdot\left(g_yp_y+g_up_u\right)^{-1}=0\end{cases}\qquad(12)$$

257 In order to determine the shadow price of non-desired output items, solving this joint cubic

258 equation system for the state above equal to zero, the shadow price model for non-desired output

259 pollutants in tourism can be determined as follows:

260 $$p_u=-p_y\cdot\left[\partial\vec{D}_0\left(x,y,u;g\right)\big/\partial u\right]\cdot\left[\partial\vec{D}_0\left(x,y,u;g\right)\big/\partial y\right]^{-1}\qquad(13)$$

261 When there are multiple desired and non-desired outputs in the tourism industry, the shadow

262 price of the $i_{th}$ desired output price is denoted by $P_{yi}$ and the shadow price of the j-th non-desired

263 output pollutant is denoted by $P_{uj}$. Using the extreme value method, it can be easily determined and

264 the shadow price model for multiple output states is expressed as follows:

265 $$p_{uj}=-p_{yi}\frac{\gamma_j+\sum_{k=1}^{K}\beta_{tk}u_{tk}+\sum_{l=1}^{L}\eta_{tl}x_{tl}+\sum_{h=1}^{H}\mu_{th}u_{th}}{\beta_j+\sum_{k=1}^{K}\beta_{tk}y_{tk}+\sum_{l=1}^{L}\delta_{tl}x_{tl}+\sum_{h=1}^{H}\mu_{th}y_{th}}\qquad(14)$$

266 The above equation is the shadow price model of pollutants emitted by energy consumption in

267 tourism, and it is relatively easy to account for the shadow price of pollutants emitted by energy

268 consumption in tourism behavior, provided that certain methods are used to achieve the estimation of

269 the model parameters.

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

271 In fact, since the shadow price model identified above is constructed using a directional distance

272 function, there are parameters in the model that reflect the magnitude of the shadow price model without

273 being able to directly use the shadow price model to determine the shadow price of non-desired output

274 pollutants. To calculate the shadow price of energy emissions from low-carbon tourism, it is necessary

275 to first estimate the parameters of the shadow price model. Because the parameters of the directional

276 distance function and the parameters of the shadow price model are the same. Therefore, the parameters

277 can be estimated by combining the two. According to the theory and method of distance function,

278 parametric linear programming method and extreme value theory can be used for parameter estimation

279 (Färe et al., 2007). In the low-carbon tourism decision system, the parameter estimation is carried out

280 using the shadow price model of tourism energy consumption $CO_2$ and harmful substance emissions.

281 First, the parametric programming model for parameter estimation is constructed based on the shadow

282 price model determined above, with the following model expressions：

283
$$f\left(x,y,u;g\right) = \min \sum\nolimits_{t=1}^{T} \sum\nolimits_{k=1}^{K} \left\{ \vec{D}_{0t}\left(x_{tk}, y_{tk}, u_{tk}; 1,1\right) - 0 \right\}$$

$$S \cdot t \cdot \begin{cases} \vec{D}_0^t\left(x_{tk}, y_{tk}, u_{tk}; 1,1\right) \geq 0 \\ \partial \vec{D}_0^t\left(x_{tk}, y_{tk}, u_{tk}; 1,-1\right) \cdot \left(\partial y_{jk}^t\right)^{-1} \leq 0 \\ \beta - \sum\nolimits_{j=1}^{J} \gamma_j = -1 \\ \beta' - \sum\nolimits_{j=1}^{J} \mu_j = 0 \\ \delta_i - \sum\nolimits_{j=1}^{J} \eta_{ij} = 0 \\ \sum\nolimits_{j'=1}^{J} \gamma_{jj'} - \mu_j = 0 \\ \alpha_{ii'} = \alpha_{i'i} \\ \beta_{jj'} = \beta_{j'j} \\ \gamma_{nn'} = \gamma_{n'n} \\ i \neq i', j \neq j', n \neq n' \end{cases} \quad （15）$$

13

284    According to the theory of directional distance function, to estimate the parameters of shadow

285    price model, the quadratic directional distance function is selected among numerous parameter

286    estimation methods to determine the parameters of shadow price model. If the starting vector of the

287    combination point of expected output and discarded expected output is determined as: g= (1, 1). The

288    tourism industry in Jiangsu Province has K internal sectors, and in this paper, the internal sectors are

289    chosen to be the tourism sectors of each prefecture-level city, then the quadratic directional distance

290    function for each sector of k in period t within the fiscal year is expressed as follows：

291
$$
\partial \vec{D}_0\left(x_{it}, y_{it}, u_{it}; 1,1\right) = \alpha_0 + \sum_{i=1}^{I} \alpha_i x_{it} + \sum_{j=1}^{J} \beta_j y_{jt} + \sum_{k=1}^{K} \gamma_k u_{kt} \frac{1}{2}\sum_{i=1}^{I}\sum_{i'=1}^{I}\alpha_{ii'} x_{it} x_{i't} +
$$
$$
\frac{1}{2}\sum_{j=1}^{J}\sum_{j'=1}^{J}\beta_{jj'} y_{jt} y_{j't} + \frac{1}{2}\sum_{k=1}^{K}\sum_{k'=1}^{K}\gamma_{kk'} u_{kt} u_{k't} + \sum_{i=1}^{I}\sum_{j=1}^{J}\delta_{ij} x_{jt} y_{jt} + \quad (16)
$$
$$
\sum_{i=1}^{I}\sum_{k=1}^{K}\eta_{ik} x_{kt} u_{kt} + \sum_{j=1}^{J}\sum_{k=1}^{K}\mu_{jk} y_{kt} u_{kt}
$$

292    Where: $r_{it}$ is the input resources of the $i_{th}$, period t. In this paper, we choose four input variables:

293    fixed asset investment in tourism, tourism service personnel in each municipality, energy

294    consumption in tourism behavior and investment in air pollution governance in tourism; $y_{it}$ is the

295    expected output of the $i_{th}$, period t. In this paper, we choose one expected output of total tourism

296    revenue in each municipality; $u_{it}$ is the non-expected output of the $i_{th}$, period t. In this paper, we

297    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

298    Shephard's directional distance function, the directional distance function is simplified based on the

299    comprehensive analysis, and the specific simplified results are as follows：

300
$$
\vec{D}_0^t\left(x_{tn}, y_{tn} + \alpha g_y, u_{tn} - \alpha g_u; 1, -1\right) = \vec{D}_0\left(x_{tn}, y_{tn}, u_{tn}; 1. -1\right) - \alpha \quad （17）
$$

301    To calculate the shortest distance from the combination point of expected pass output and non-

302    expected output to the combination function, it is necessary to determine the extreme value point of

303    the combination function. Extreme value theory can be used to find the second-order partial

304    derivatives of the relevant variables of the output combination function, and the relevant system of

305    joint cubic equations can be established based on the results of solving the partial derivatives, and the

306    parameters of the shadow price model can be determined by solving the system of equations. Then,

307    using mathematical methods to perform partial derivative operations on the above system of

308    equations, the results of the operations are simplified to obtain the following simplified system of

309    equations：

310
$$\begin{cases} \beta - \sum_{j=1}^{J} \gamma_j = -1 \\ \beta' - \sum_{j=1}^{J} \mu_{ij} = 0 \\ \delta - \sum_{j=1}^{J} \eta_j = 0 \\ \sum_{j'=1}^{J} \gamma_{jj'} - \mu_j = 0 \end{cases} \qquad (18)$$

311    The constraints of the parametric planning equation are imposed on the non-negative and

312    monotonicity properties of the directional distance function, which allows for a negative shadow price

313    of pollutants emitted by tourism energy consumption. Since $\partial \vec{D}_0(r_{it}, y_{it}, u_{it}; 1,1) =$

314    $f(x, y, u; g) \geq 0$ , and the corresponding $\partial \vec{D}_0^t(r_{tk}, y_{tk}, u_{tk}; 1, -1) \cdot (\partial y_{jn}^t)^{-1} = \beta + \beta' y_k +$

315    $\sum_{i=1}^{I} \delta_i r_{ik} + \sum_{j=1}^{J} \mu_j u_{jk} \leq 0$ , likewise have: $\partial \vec{D}_0^t(r_{tn}, y_{tn}, u_{tn}; 1, -1)\partial u_{kn}^t = \gamma_j + 0.5 \cdot$

316    $\sum_{j'}^{J} \gamma_{jj'} u_{j'k} + \sum_{i=1}^{I} \eta_{ij} r_{ik} + \mu_j y_k \geq 0$. Therefore, based on these three constraints it is possible to

317    characterize the directional distance function as a quadratic function using Chambers' method and to

318    estimate the quadratic function to a second-order approximation. That is, the parameters of the

319    directional distance function are determined by using the method of solving for the partial derivatives

320    of the quadratic function, and the specific solution results are detailed in the following expressions：

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

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

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

324   Using the above set of equations, it is possible to achieve the estimation of the shadow price

325   model of non-desired outputs of tourism energy consumption. By substituting the already estimated

326   model parameters back into equation (14), it is easy to calculate the shadow price of non-desired

327   outputs of tourism energy consumption and achieve the accounting of economic losses caused by the

328   emissions of non-desired outputs of tourism energy consumption.

## 3. Results and Discussion

### 3.1 Results of measuring the shadow price of pollutants

331   Jiangsu Province is a major economic province in China, as well as a major tourist province.

332   The current status of non-expected pollutant emissions of tourism behavior energy consumption in

333   Jiangsu province and 13 prefecture-level cities as well as the current status of air pollution

334   management have been analyzed in detail above. In order to effectively measure the air pollution loss

335   of non-expected output of tourism energy consumption in Jiangsu province, the relevant basic data

336   have been revised in the process of determining the basic data. For example, for the issue of fixed

337   asset investment in tourism in Jiangsu Province, for the development of attractions historical and

338   cultural relics repair and other acts of investment is relatively concentrated, most statistics of fixed

339   asset investment does not take into account the value of classic assets, which makes the book value

340   of tourism fixed asset investment shows too much fluctuation. To solve this problem this paper

341   combines the smoothing of tourism fixed asset investment for the study year as well as the

342   depreciation method of homogenization, which reduces the fluctuation of tourism fixed asset

343   investment and facilitates the calculation of air pollution loss measures for the non-desired output of

344   tourism energy consumption；For the number of people in the tourism industry at the end of the

345   period, there are more people actually performing services than this result, and this paper does not

346   consider indirect tourism service workers, nor indirect government-related personnel, but mainly

347   those directly involved in tourism services within the tourism industry; energy consumption is not an

348  actual energy consumption statistic, but a discounted result of energy consumption of tourism

349  behavior is used; The volatility of the book value of the EPC investment is also significant, and this

350  paper uses the actual EPC investment tourism revenue share for the calculation and correction of the

351  absorption; The scale of non-desired pollutant emissions uses the results of the accounting. The input-

352  output base information of the measurement of air pollution loss of non-expected output of tourism

353  energy consumption in Jiangsu Province determined on this basis is detailed in Table 1.

354  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 |

355

357  In Table 1, $X_{1j}$ is total tourism revenue（100 million yuan）, $X_{2j}$ is investment in tourism fixed

358  assets, $X_{3j}$ is number of people in the tourism industry at the end of the period (10000 people), $X_{4j}$ is

359  energy input (10000 tons of standard coal), $X_{5j}$ is the investment in air pollution governance (100

360  million yuan), $X_{6j}$ is $CO_2$ emission scale (10000 tons), $X_{7j}$ is $SO_2$ emission scale (10000 tons), $X_{8j}$

361  is NOx emission scale 10000 tons), $X_{9j}$ is CO emission scale (10000 tons), $X1_{0j}$ is $PM_{2.5}$ emission

362  scale (10000 tons), $X_{11j}$ is $PM_{10}$ emission scale (10000 tons), $X_{12j}$ is $O_3$ emission scale (10000 tons),

363    $X_{13j}$ is Pb emission scale million (10000 tons). According to the shadow price model and the results

364    of the analysis of the parameter determination method, the magnitude of the parameters of the

365    directional distance function depends on the number and status of the input and output variables of

366    the production decision system. In this paper, we choose: four input variables such as fixed assets,

367    number of employees, energy consumption, and investment in air pollution governance; one desired

368    output variable, total output value; and eight non-desired energy pollutant output variables, $CO_2$

369    emission scale, $SO_2$ emission scale, $NO_2$ emission scale, CO emission scale, $PM_{10}$ emission scale,

370    $PM_{2.5}$ emission scale $O_3$ emission scale, and Pb emission scale. According to the shadow price model

371    estimation method for non-expected output pollutants, there are 139 parameters of variables that need

372    to be estimated under this combination of tourism inputs and outputs. In order to reduce the workload

373    of the shadow price model parameter estimation, this paper introduces some technical methods to

374    simplify the parameter estimation according to the nature and structure of the equation, and the

375    parameter estimation is calculated using Lngo18.0.44 software. It is a simple and powerful linear and

376    nonlinear solver with a complete integrated installation package for building and editing fully

377    functional environments for solving systems of nonlinear equations of all kinds, which makes

378    complex calculations very easy. In this paper, based on the above constructed shadow price model

379    parameter estimation equations (15) - (18), 139 model parameters are easily determined by inputting

380    the underlying data into the input of Lngo18.0.44 software, on the basis of comparing the model

381    parameters with the shadow price model (14) and the directional distance function (16). In addition

382    to fully utilizing various specific conditions, parameter estimation in shadow price models also

383    involves various specific methods, such as calculating or allocating individual parameter values

384    during the process of determining specific parameters. Based on comprehensive analysis, use

385    computers and specialized software to calculate and determine, and the specific shadow price model

386    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 |
|---|---|---|---|---|---|---|---|---|---|
| $\alpha_0$ | -0.2136 | $\gamma_6$ | -0.1295 | $\gamma_{42}$ | -0.1851 | $\gamma_{76}$ | -0.1015 | $\eta_{26}$ | 0..0975 |
| $\alpha_1$ | 0.1216 | $\gamma_7$ | -0.1214 | $\gamma_{43}$ | -0.1015 | $\gamma_{77}$ | -0.1192 | $\eta_{27}$ | 0.1128 |
| $\alpha_2$ | 0.3126 | $\gamma_8$ | 0.1124 | $\gamma_{44}$ | 0.1523 | $\gamma_{78}$ | 0.4217 | $\eta_{28}$ | -0.3482 |
| $\alpha_3$ | 0.1237 | $\gamma_{11}$ | 0.4262 | $\gamma_{45}$ | 0.0657 | $\gamma_{81}$ | 0.3616 | $\eta_{31}$ | -0.6217 |
| $\alpha_4$ | -0.2417 | $\gamma_{12}$ | 0.2131 | $\gamma_{46}$ | 0.1837 | $\gamma_{82}$ | -0.3224 | $\eta_{32}$ | 0.0983 |
| $\alpha_{11}$ | 0.1643 | $\gamma_{13}$ | -0.1072 | $\gamma_{47}$ | 0.1227 | $\gamma_{83}$ | 0.2816 | $\eta_{33}$ | -0.2178 |
| $\alpha_{12}$ | 0.2021 | $\gamma_{14}$ | 0.2857 | $\gamma_{48}$ | 0.1675 | $\gamma_{84}$ | -0.0416 | $\eta_{34}$ | 0.2073 |
| $\alpha_{13}$ | 0.1825 | $\gamma_{15}$ | -0.1636 | $\gamma_{51}$ | 0.1889 | $\gamma_{85}$ | -0.0672 | $\eta_{35}$ | 0.1827 |
| $\alpha_{14}$ | -0.2162 | $\gamma_{16}$ | -0.2124 | $\gamma_{52}$ | 0.2107 | $\gamma_{86}$ | 0.0925 | $\eta_{36}$ | 0.3016 |
| $\alpha_{21}$ | 0.0448 | $\gamma_{17}$ | 0.2122 | $\gamma_{53}$ | 0.2078 | $\gamma_{87}$ | 0.1066 | $\eta_{37}$ | 0.0923 |
| $\alpha_{22}$ | 0.1627 | $\gamma_{18}$ | 0.3016 | $\gamma_{54}$ | 0.1886 | $\gamma_{88}$ | 0.0886 | $\eta_{38}$ | -0.8621 |
| $\alpha_{23}$ | -0.2372 | $\gamma_{21}$ | 0.2458 | $\gamma_{55}$ | 0.0985 | $\delta_{11}$ | -0.0768 | $\eta_{41}$ | 0.0627 |
| $\alpha_{24}$ | -0.3327 | $\gamma_{22}$ | 0.2638 | $\gamma_{56}$ | 0.0674 | $\delta_{21}$ | 0.0547 | $\eta_{42}$ | 0.0875 |
| $\alpha_{31}$ | 0.2751 | $\gamma_{23}$ | -0.2236 | $\gamma_{57}$ | -0.0768 | $\delta_{31}$ | 0.0268 | $\eta_{43}$ | 0.1027 |
| $\alpha_{32}$ | 0.3016 | $\gamma_{24}$ | -0.1827 | $\gamma_{58}$ | -0.0786 | $\delta_{41}$ | 0.1027 | $\eta_{44}$ | -0.7891 |
| $\alpha_{33}$ | 0.0981 | $\gamma_{25}$ | 0.2151 | $\gamma_{61}$ | 0.0864 | $\eta_{11}$ | -0.1926 | $\eta_{45}$ | 0.0527 |
| $\alpha_{34}$ | -0.2138 | $\gamma_{26}$ | 0.1625 | $\gamma_{62}$ | 0.0579 | $\eta_{12}$ | 0.0279 | $\eta_{46}$ | 0.0602 |
| $\alpha_{41}$ | -0.1826 | $\gamma_{27}$ | 0.2016 | $\gamma_{63}$ | 0.0874 | $\eta_{13}$ | 0.0653 | $\eta_{47}$ | -0.1295 |
| $\alpha_{42}$ | 0.2136 | $\gamma_{28}$ | 0.3127 | $\gamma_{64}$ | 0.1092 | $\eta_{14}$ | -0.0753 | $\eta_{48}$ | -0.1214 |
| $\alpha_{43}$ | 0.1627 | $\gamma_{31}$ | 0.1627 | $\gamma_{65}$ | 0.1627 | $\eta_{15}$ | 0.1627 | $\mu_{11}$ | 0.1124 |
| $\alpha_{44}$ | -0.2372 | $\gamma_{32}$ | -0.2372 | $\gamma_{66}$ | -0.2372 | $\eta_{16}$ | -0.2372 | $\mu_{12}$ | 0.4262 |
| $\beta_1$ | -0.3327 | $\gamma_{33}$ | -0.3327 | $\gamma_{67}$ | -0.3327 | $\eta_{17}$ | -0.3327 | $\mu_{13}$ | 0.2131 |
| $\beta_{11}$ | 0.2751 | $\gamma_{34}$ | 0.2751 | $\gamma_{68}$ | 0.2751 | $\eta_{18}$ | 0.2751 | $\mu_{14}$ | -0.1072 |
| $\gamma_1$ | 0.3016 | $\gamma_{35}$ | 0.3016 | $\gamma_{71}$ | 0.3016 | $\eta_{21}$ | 0.3016 | $\mu_{15}$ | 0.2857 |
| $\gamma_2$ | 0.0981 | $\gamma_{36}$ | 0.0981 | $\gamma_{72}$ | 0.0981 | $\eta_{22}$ | 0.0981 | $\mu_{16}$ | -0.1636 |
| $\gamma_3$ | -0.2138 | $\gamma_{37}$ | -0.2138 | $\gamma_{73}$ | -0.2138 | $\eta_{23}$ | -0.2138 | $\mu_{17}$ | -0.2124 |
| $\gamma_4$ | -0.1826 | $\gamma_{38}$ | -0.1826 | $\gamma_{74}$ | -0.1826 | $\eta_{24}$ | -0.1826 | $\mu_{18}$ | 0.2122 |
| $\gamma_5$ | 0.2136 | $\gamma_{41}$ | 0.2136 | $\gamma_{75}$ | 0.2136 | $\eta_{25}$ | 0.2136 | | |

388     In the international process of model parameters, because there are some differences between

389     the shadow price model constructed in this paper and the requirements of the directional distance

390 function and Lngo18.0.44 software, the parameter estimation process is estimated separately for the

391 non-conforming elements, making it impossible for the determined model parameters to fully

392 conform to the actual situation. After the analysis of the estimated parameters and the trial operation

393 of the model, it is verified that the estimated parameters basically meet the requirements of the shadow

394 price model and the validity of the shadow price model is confirmed. In order to effectively calculate

395 the shadow price of non-expected output pollutants of tourism energy consumption in Jiangsu

396 Province, the above parameter estimation results are substituted into (16) quadratic directional

397 distance function to determine the shortest distance, and then use formula (14) to calculate the shadow

398 price of eight pollutants generated by tourism behavior energy consumption as detailed in Table 3.

399 **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 |

400 The above is the result of the calculation of the shadow price of non-expected output harmful to

401 tourism energy consumption in Jiangsu Province, the unit of measurement is yuan, in order to reduce

402 the error, the individual results of the calculation of the coefficient correction.

403 3.2 **Measurement results of air pollution loss of pollutants**

404 On the basis of the calculation of the shadow price of pollutants for non-expected output of

405 energy consumption in tourism behavior, the air pollution loss of non-expected pollutant emissions

406 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

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.

424

**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 |

425 Unit: Ten thousand yuan

426 The above results of air pollution loss apportioned using the number of tourists as a percentage

427 may have some errors with the actual results, but this does not affect the results of the evaluation of

428 the air pollution governance effect of carbon emissions from tourism energy consumption in each city

429 later in this paper, and the revised air pollution loss accounting results are used in the evaluation.

430 ### 3.4 Discussion of factors influencing air pollution loss in low carbon tourism

431 In this paper, the air pollution loss measurement of low carbon tourism energy consumption

432 pollutant emissions in Jiangsu province is measured from two aspects: the type of pollutants in the

433 province and by prefecture-level cities. From the analysis of the measurement results of air pollution

434 loss of energy consumption pollutants of tourism, the curve family is drawn in the right-angle

435 coordinate system using the measurement results in Table 3, which can obviously show the

436 composition and changes of air pollution loss generated by different pollutants of low-carbon tourism

437 in Jiangsu province, and the specific situation is shown in Figure 2.
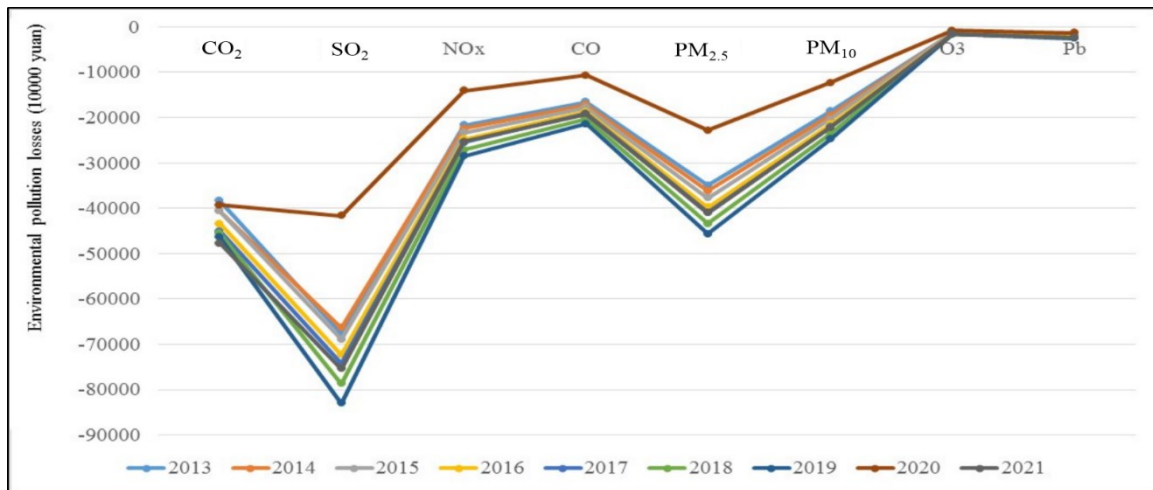
From the above graph can be clearly low to see that the air pollution loss of various pollutants of low-carbon tourism energy consumption in Jiangsu Province, the highest in 2019 and the lowest in 2020, which is mainly influenced by the epidemic; In terms of the air pollution loss of different pollutants, 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.
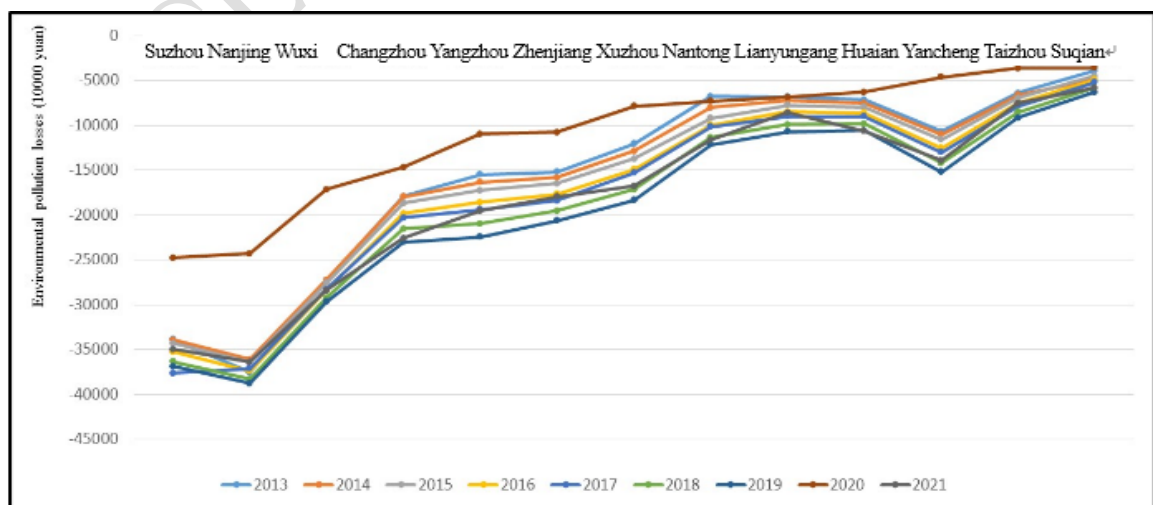


Fig. 3. Change in air pollution losses of pollutants by prefecture-level cities

23

451     It can be clearly seen from Figure 3 that the air pollution losses of different prefecture-level cities

452     in Jiangsu Province in terms of energy consumption pollutant emissions from tourism are the lowest

453     in Suqian and the highest in Nanjing, and the air pollution losses of other prefecture-level cities are in

454     the following order: Taizhou, Huai'an, Lianyungang, Nantong, Xuzhou, Yancheng, Zhenjiang,

455     Yangzhou, Changzhou, Wuxi and Suzhou; From the annual changes, the tourism energy consumption

456     air pollution loss of each prefecture-level city is the highest in 2019 and the lowest in 2020. Therefore,

457     managers should develop corresponding strategies according to the change pattern of the above two

458     measurement results to promote the sustainable reduction of economic loss of low-carbon tourism

459     energy consumption and pollutant emission in Jiangsu Province.

460     **4. Conclusions and Recommendations**

461     In order to explore the air pollution loss measurement method of low-carbon tourism energy

462     consumption and pollutant emissions in Jiangsu Province, this paper selects the air pollution loss

463     measurement of low-carbon tourism energy consumption and pollutant emissions in 13 prefecture-

464     level cities in Jiangsu Province based on the research background analysis, literature review and

465     research design. By reconstructing the shadow price model of air pollution loss of pollutants, the air

466     pollution loss measurement of energy consumption pollutant emissions in 13 tourist areas in Jiangsu

467     province was studied by using the basic information provided by the government. The study found

468     that: the air pollution loss caused by the emission of eight pollutants from low-carbon tourism energy

469     consumption in Jiangsu Province ranged from 142.92 million yuan to 253.93 million yuan, and the

470     air pollution loss of low-carbon tourism energy consumption and emission in 13 prefecture-level

471     cities was the largest in Nanjing, which produced an air pollution loss of 387.69 million yuan in 2019,

472     and the lowest air pollution loss year was 2020, with an air pollution loss of 2430.02 million yuan.

473     Therefore, to reduce the air pollution loss of 13 prefecture-level cities in Jiangsu Province as well as

474     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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