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Green corridors and regional economic integrations for sustainable development, 2nd Edition

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Green corridors and regional economic integrations for sustainable development, 2nd Edition

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Regional Non-point Source Pollution Control Method: A Design of Ecological Compensation Standards

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Reasonable ecological compensation standard is the key to solve farmland non-point source pollution. In the design of compensation standards, the current investigation included ecological benefits in selecting the experimental method. The Multinomial Logit model is used to analyze the willingness of farmers to receive compensation for non-point source pollution control of cultivated land. The results are as follows: 1) Financial compensation can effectively stimulate farmers' willingness to control non-point source pollution. 2) The willingness of farmers to participate in the ecological compensation is greater when there prevails a higher level of risk preferences and higher understanding of farmland non-point source pollution control policy. Also, willingness is higher in younger, highly educated, and highly involved in a part-time family business with higher recognition degree in the ecological function of farmland non-point source pollution control. 3) The difference in treatment measures and compensation methods should be included in the standard compensation design. Therefore, the design of the ecological compensation standard should take into account the economic loss and ecological benefits of farmers at the same time, and environmental protection publicity and education for farmers can also be carried out with the help of modern media.

Keywords: cultivated land non-point pollution, pollution control, ecological benefit, environmental protection, compensation standard

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INTRODUCTION

The cultivated land provides people with a survival guarantee and provides peasant households with an employment guarantee. The cultivated land has economic and social value in China with a large agricultural population and plays an essential role in social stability (Ozdemir, 2020; Sharma and Mahajan, 2019). Meanwhile, the cultivated land also has ecological benefits such as water conservation, climate regulation, and biodiversity maintenance. However, with the socio-economic development, peasant households use a large number of chemical fertilizers and pesticides to pursue higher agricultural output, which inevitably leads to the issue of non-point source pollution[1] of cultivated land (Lu et al., 2020a). The cultivated land is a non-renewable resource with high pollution frequency, wide harm range, and control difficulty. Thus it has gradually evolved

[1]It mean diffusion of contamination or pollution in the water/air that does not originate from a single discrete source. This type of pollution is often cause cumulative effect of small amounts of contaminants that dispersed on a large area. For example excess use of fertilizers, herbicides and insecticides diffuse in agricultural lands and air

into a worldwide issue. To ensure the sustainable and sound development of China's agriculture, non-point source pollution of cultivated land needs to be solved urgently.

In terms of the causes of pollution, reducing the use of chemical fertilizers and pesticides and the discharge of agricultural wastes from the source is the most effective measure to improve the ecological value of the cultivated land system. However, peasant households' enthusiasm for adopting the source mentioned above is low due to the shortage of technology and the risk of yield reduction (Valentine, 2014). Therefore, ecological compensation has become an effective economic means to adjust the relationship between stakeholders and realize the internalization of external benefits. Peasant households are mainly encouraged to actively reduce the application of chemical fertilizers and pesticides and reduce agricultural waste discharge in the production process by giving them economic compensation, thereby promoting the coordinated development of cultivated land ecosystem protection and peasants' steady and increasing income. Therefore, adopting ecological compensation standards by considering the ecological benefits is a suitable method that shows the motivation of doing this research.

Ecological footprint cause ravid environmental degradation (Ulucak et al., 2020). Stated that ecological footprint caused rapid environmental degradation and discriminated liabilities for countries, while the government remains unnoticed environmental conservation either in policy priorities and in academic literature. Moreover (Kassouri and Altıntaş, 2020), highlighted the strong association between ecological footprints and human development from the panel data of thirteen countries and demonstrated that economic institutions can play a crucial role in the mitigation of such trade-off (Zheng et al., 2021). suggested the mechanism of ecological compensation for the solution of environmental and economic dilemmas in order to achieve sustainable development. By using panel data, their results showed that industrial areas tend to be advanced and rational after the implementation of the ecological compensation policy.

The concept of ecological compensation was put forward with the outbreak of the environmental crisis in western countries in the 1960s and 1970s (Lu et al., 2016; Meng et al., 2016). With the continuous improvement of material living standards, the ecological environment was also extensively damaged. Thus people began to explore the path of sustainable development, and all sectors of society raised ecological compensation (Gao et al., 2019; Lu et al., 2020b). China's industrialization process starts late, but the deterioration rate of the ecological environment in China in recent years is no less than that of western developed countries, which seriously threatens people's safety and future development. Therefore, China pays more and more attention to the research on ecological compensation issues and carries out many practical activities.

As for the research on ecological compensation of cultivated land, some studies in the U.S. show that fallow is the main way for soil protection (Xu et al., 2019; Chen et al., 2020a). Peasant households can apply to the government and sign long-term contracts according to their actual situation and wish to convert those ecologically fragile cultivated land into grassland and woodland or stop farming. The European Union (EU) implements graded ecological compensation for cultivated land. Baylis K stated that each EU member state determines its minimum level of good farming practice (GFP) and obtains government subsidies in the first stage, including agricultural subsidies and price support (Chen et al., 2018). Peasants can obtain more subsidy support accordingly if making continuous efforts to increase GFP beyond the baseline level. In this way, the EU ecological compensation of cultivated land has a strong correlation with the quality of cultivated land. The higher the quality of cultivated land, the more compensation can be obtained. According to the practice, this policy can better encourage peasants to improve cultivated land quality and protect cultivated land resources.

There are some foreign experiences in ecological compensation that we can learn from (Lu et al., 2021; Zhao et al., 2021). For example, it systematically explains why compensation shall be made and who shall make compensation in theory. However, the compensation standard cannot be copied due to the different national and agricultural conditions. Many domestic scholars have drawn lessons from the research results of foreign scholars in their theoretical discussions on related issues. At the same time, the compensation standards are quite different according to their different research fields and time and space (Deng et al., 2017; Guan et al., 2018). Given the research trends of ecological compensation in China and other countries, this paper will fully absorb the experience of ecological compensation in various fields in China and other countries. The actual situation will be introduced into the design of compensation standards for non-point source pollution control of cultivated land.

Therefore, it is necessary to formulate a reasonable compensation standard for non-point source pollution control of cultivated land to generate effective incentives for peasant households and conform to the principle of minimizing social expenditure. The various costs of peasant households' ecological protection behavior and the value of cultivated land ecosystem obtained by peasant households due to environmental improvement shall be considered in the compensation standard to avoid the low compensation efficiency caused by high compensation standards. It is difficult to evaluate the ecological benefits of cultivated land by the existing market value evaluation methods. Thus the selection experiment method, that is, the non-market value evaluation method based on the hypothetical market will be used in this paper to quantify the economic losses and ecological benefits obtained by peasant households in the process of non-point source pollution control of cultivated land, and then to obtain the ecological compensation standard for non-point source pollution control of cultivated land that takes into account the interests of peasant households and the principle of minimizing social expenditure.

THEORETICAL ANALYSIS AND RESEARCH METHODS

Necessity of Considering Ecological Benefits in Compensation Standards

Peasant households enjoy the ecosystem value of cultivated land while participating in pollution control of cultivated land (Lu et al., 2019a). To maximize the effectiveness of control policies, it is necessary to incorporate ecological benefits into the compensation standard for non-point source pollution control of cultivated land.

Assuming that the utility function of peasant households is U = U (A, E), the production function of agricultural products is F (X), and the production function of ecological products is G (Y). Where, A represents the net income of agriculture, E represents the ecological products provided by non-point source pollution control of cultivated land, X is the input factor of agricultural product production, its unit cost is W, Y is the input factor of non-point source pollution control of cultivated land, and its unit cost is R. In addition, assuming that P1 is the price vector of unit agricultural products and P2 is the price vector of ecological products, its economic meaning is the ecological benefits obtained by peasant households. Utility function U (A, E), production function of agricultural products F (X), and production function of ecological products G (Y) are monotone increasing concave functions respectively. To ensure the accuracy of the theoretical model, the following assumptions are put forward in this paper:

H1: Peasant households are rational economic men who clearly understand their wishes, preferences, and behavior results, and the purpose of their economic behavior is to maximize welfare.

H2: There is only one peasant household in the market, and the ecological products E enjoyed by the peasant household depend on the number of ecological products G (Y) provided by individuals; thus there is E = G (Y).

H3: Assuming that the benchmark state t = 0, the agricultural income is A = A0, the input for non-point source pollution control of cultivated land is Y0 = 0, that is, G (Y0) = 0, and the utility level before participating in non-point source pollution control of cultivated land is U0; at the time of t = 1 for ecological compensation of non-point source pollution control of cultivated land, A ≥ A0, Y ≥ 0, U ≥ U0.

The basic principle of ecological compensation is that the welfare level of peasant households will not decline after participating in the non-point source pollution control of cultivated land (Guan et al., 2018). Therefore, the economic model for peasant households to participate in the decision-making of non-point source pollution control of cultivated land is as follows:

$$\begin{cases} \text{Max } U(A, E) \\ \text{s.t.} P1F(X) + P2G(Y) - WX - RY \geq A0 \\ X, Y \geq 0 \end{cases} \quad (1)$$

Forming a Lagrangian Function:

$$L = U(A, E) + \lambda[P1\,F(X) + P2\,G(Y) - WX - RY - A0] \quad (2)$$

According to Kuhn-Tucker first-order conditions, we can obtain the following:

$$\frac{\partial L}{\partial X} \leq 0,\ X \geq 0,\ \text{and } X\frac{\partial L}{\partial X} = 0$$

$$\frac{\partial L}{\partial Y} \leq 0,\ Y \geq 0,\ \text{and } Y\frac{\partial L}{\partial Y} = 0 \quad (3)$$

$$\frac{\partial L}{\partial \lambda} \geq 0,\ \lambda \geq 0,\ \text{and } \lambda\frac{\partial L}{\partial \lambda} = 0$$

According to the principle of complementary slackness, when = 0 and X > 0, Y > 0:

$$\frac{\partial L}{\partial X} = \frac{\partial UA}{\partial A}\left[P1\,F'(X) - W\right] = 0 \quad (4)$$

$$\frac{\partial L}{\partial Y} = \frac{\partial UA}{\partial A}[P2\,G(X) - R] + \frac{\partial UE}{\partial E}G(X) = 0 \quad (5)$$

According to **Formulas 4, 5**, we can obtain

$$P2 = \frac{R}{G}(X) - \frac{\partial UE}{\partial E}/\frac{\partial UA}{\partial A} \quad (6)$$

Similarly, if

$$P2 < \frac{R}{G}(X) - \frac{\partial UE}{\partial E}/\frac{\partial UA}{\partial A}, \quad (7)$$

we can obtain Y = 0.

The results show that: marginal compensation standard = cost per unit ecological product - monetization utility per unit ecological product. It can be concluded that the difference between the economic cost of peasant households' participation in pollution control and the ecological benefits obtained by peasant households due to ecological improvement is the minimum compensation standard to encourage peasant households to participate in pollution control. Peasant households will not be willing to participate in the non-point source pollution control of cultivated land when the compensation standard is lower than this difference. Moreover, in the current investigation, we assumed that the farmers have the same land size and did not categorize the farmers into groups (large/small farmers). So we assumed that there is no heterogeneity prevails.

Research Methods

The ecological benefits of cultivated land are difficult to be evaluated by the existing market value evaluation methods. The selection experiment method will be used in this paper to evaluate and measure the reasonable compensation standard (Chen et al., 2020b). The selection experiment method is based on the hypothetical market to obtain stakeholders' willingness to pay or be compensated for cultivated land's ecological improvement. Assuming that the peasant household i selects the non-point source pollution control scheme m of cultivated land from the j attribute combination schemes of the selection set, the utility obtained is U_{im}, including the deterministic term V_{im} and the random term ε_{im}:

$$U_{im} = V_{im} + \varepsilon_{im}$$

The basis for the peasant household i to select scheme m is $U_{im} > U_{in}$ (m, n ∊ j, m ≠ n). Assuming that D is the combination of all selection sets, the probability of selection is as follows:

$$\text{Pim} = \text{prob}\left(V_{im} + \varepsilon_{im} > V_{in} + \varepsilon_{in}, \forall j \in D, n \neq m\right)$$
$$= \text{prob}\left(V_{im} - V_{in} > \varepsilon_{in} - \varepsilon_{im}, \forall j \in D, n \neq m\right)$$

To obtain the exact expression of the above formula, assuming that ε obeys Gumbel distribution and independent identical distribution, the Multinomial Logit model is obtained. At this time, the probability of consumer i selecting scheme m is as follows:

$$\text{Prob}\,(\text{im}) = \frac{\exp(\lambda \text{Vim})}{\sum_{ij} \exp(\lambda \text{Vij})} \tag{8}$$

The linear function expression of observable utility V_{im} is as follows:

$$V_{im} = \alpha ASC_{im} + \beta x_{im} + \gamma i ASC_{im} z_{im} \tag{9}$$

In the above formula, α, β and γ_i are the parameter matrices to be estimated, ASC_{im} is a specific alternative constant. when the alternative scheme is the benchmark scheme, ASC is assigned a value of 1. At this time, the coefficient α_i of ASC is the possibility of peasant households selecting the benchmark scheme. If α_i is positive, peasant households are unwilling to change the traditional production mode; on the contrary, it means that peasant households are willing to accept the non-point source pollution control scheme of cultivated land. X_{im} represents the vector-matrix of non-point source pollution control measures of cultivated land; z_{im} is the social information characteristic variable, family resource endowment, psychological perception variable, and policy cognition variable of the experiment participants; $ASC_{im}z_{im}$ is a cross term of specific alternative constant and social information characteristic variables, reflecting the influence of social information characteristic variables on participants' selection of traditional production methods.

The implied price is the marginal willingness of experiment participants to be compensated for a single non-point source pollution control measure of cultivated land, with the formula as follows:

$$IP_a = MWTA_a = -\frac{\beta_a}{\beta_b} \tag{10}$$

In **Formula 10**, β_a and β_b represent the coefficient of non-point source pollution control measures of cultivated land and compensation respectively. The greater IP, the higher the marginal willingness of peasant households to be compensated for non-point source pollution control measures of cultivated land.

As the change of peasant households' welfare after recovering from the benchmark scheme to the specific treatment situation, the compensation surplus is used to calculate the willingness of peasant households to be compensated WTA for non-point source pollution control scheme m of cultivated land in this paper, with the specific calculation formula as follows:

$$WTA_m = CS_m = -\frac{1}{\beta b}\left(V_0 - V_m\right) \tag{11}$$

Where V_0 and V_m represent the utility level of peasant households under the benchmark scheme and control scheme m, respectively.

FIGURE 1 | Schematic diagram of areas investigated.

EXPERIMENTAL DESIGN

Data Source

The data of this paper comes from the field investigation in Changsha County, Wangcheng District, Liuyang City, Ningxiang City, Xiangtan County, and Xiangxiang City, Hunan Province (Lu et al., 2019a). A total of 289 questionnaires were distributed and collected, of which 238 were valid questionnaires. The investigation objects are mainly peasant households who have participated in cultivated land management activities and have certain expression abilities.

According to **Figure 1**, the areas investigated are mainly distributed in Changsha City and the surrounding two counties and cities. In recent years, the agricultural economy of Changsha City has developed rapidly, but the non-point source pollution of cultivated land caused by the surge and unreasonable use of agricultural inputs such as chemical fertilizers and pesticides, as well as the unreasonable disposal of agricultural wastes and domestic garbage, cannot be ignored. According to statistics, the proportion of high-yield farmland in cultivated land of Hunan Province has dropped from 34% in the 1970s to 26% at present due to the expansion and spread of agricultural non-point source pollution, and the area of water and soil loss has more than doubled compared with that in the 1960s (Lu et al., 2019b; Chen et al., 2019). Wetland resources, especially Dongting Lake Wetland, are suffering from both natural and man-made damage. 26% of cultivated land, 27% of farmland irrigation water, and 25% of farmland atmosphere have been polluted to varying degrees in Hunan Province, and more than 60% of river

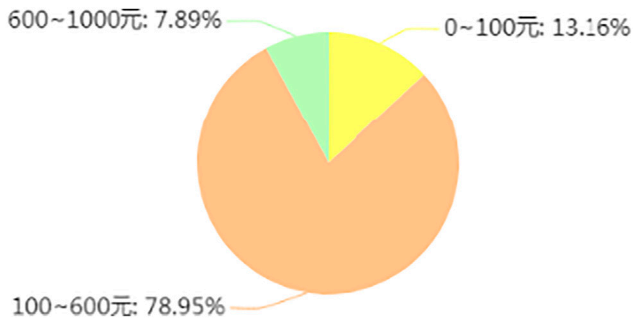

FIGURE 2 | Amount of peasant households' willingness to be compensated.

sections in the four water systems including Xiangjiang River, Zijiang River, Yuanshui River, and Lishui River have not met the requirements of fishery water quality standards (Do et al., 2019; Hong et al., 2020). Therefore, Changsha City and its surrounding counties and cities are selected as investigation objects in this paper. The compensation standard for non-point source pollution control of cultivated land is calculated, which helps to improve the local ecological environment.

Selection of Experiment Attribute and Status Value Design

In this investigation, the specific situational question designed is "Assuming that the government gives your family a certain amount of economic compensation to encourage the reduction of the use of chemical fertilizers and pesticides in the planting process of cultivated land, which scheme would you select after comprehensively considering the ecosystem value, economic loss, and compensation amount brought to your family by non-point source pollution control of cultivated land?" In order to enhance the scenario reliability, the attributes and status values of chemical fertilizer application reduction, pesticide application reduction, agricultural waste recovery, and compensation amount are selected to form attributes and status values.

Through in-depth investigation, 95% of peasant households are willing to adopt a safe and cleaner production mode under certain economic compensation from the government, which shows that most of the peasant households are willing to improve the cultivated land environment with compensation. By taking rice planting as an example, these peasants who are willing to be compensated believe that the compensation per mu of land shall be between RMB 0 and RMB 1,000 as shown in **Figure 2**. However, pre-investigation shows that the yield of rice will be reduced by about half if chemical fertilizers and pesticides are not applied. The average income per mu of ordinary rice is RMB 1,055. In case of being converted according to this standard, about RMB 530 will be lost if chemical fertilizers and pesticides are not applied. Therefore, the upper limit of compensation amount is set at RMB 600 and divided into 6 state values, as shown in **Table 1**.

The source control technology of non-point source protection of cultivated land is mainly to try not to use chemical products such as chemical fertilizers and pesticides in the production process and recycle agricultural wastes such as straw. Therefore, it is formulating four attributes: chemical fertilizer application reduction, pesticide application reduction, and agricultural waste recovery rate. According to international fertilizer application standards (Dai et al., 2021; Yin et al., 2021), China needs to reduce the application of chemical fertilizer per *mu* by about 75% to reach the average world level and reduce the application by about 50% to reach the internationally recognized safety ceiling. Thus, four status values are set, as shown in **Table 1**.

The questionnaire is designed for investigation according to the determined attributes and status values of non-point source pollution control of cultivated land. The three improvement measures and compensation amounts in the above table have 4, 4, 2, and 7 state values, respectively, which will produce $(4 \times 4 \times 2 \times 7)\ 2 = 50{,}176$ possible selection sets. However, it is challenging to realize that in the actual investigation. Therefore, 12 representative experimental combinations are obtained through orthogonal experimental design, as shown in **Table 2**.

RESULT AND ANALYSIS

Descriptive Analysis of Sample Characteristics

As shown in **Table 3**, these 238 peasant households are mainly men, accounting for 87.39% of the total samples. The investigated peasant households involve all age groups, including 59 under 35 years old, 62 over 60 years old, and 117 between 35 and 60 years old, accounting for 49.16% of the total samples. The educational level of the investigated peasant households is generally not high. Only one person has an education level of university or above, accounting for 0.42% of the total samples, 44 have an education level of high school, accounting for 18.49%. In contrast, more people have an educational level of junior high school and primary school, 115 and 78, respectively, accounting for 48.32 and 32.77% of the total samples. There are 141 people whose household income comes from working, accounting for 59.24%. The number of people whose income comes from farming and doing business is equivalent, 45 and 48, respectively. There are four people who rely on government relief, accounting for 1.68% of the total samples. There are 49 households with an annual household income of less than RMB 10,000, accounting for 20.59%, 62 households with an annual income of RMB 10,000–30,000, accounting for 26.05%, 69 households with an annual income of RMB 30,000–50,000, accounting for 28.99%, and 58 households with an annual income of more than RMB 50,000, accounting for 24.37%.

Estimated Results of MNL Model

The estimated results are shown in **Table 4**. Both models pass the significance test of 1%, with consistent estimation coefficients, which shows that the estimated results are robust. In addition, the fitting effect of Model 2 is better than that of Model 1 through the likelihood ratio test. Thus the results of model 2 are analyzed in this paper.

TABLE 1 | Attributes and status values.

Measures	The basis for attribute selection	Status value
Chemical fertilizer application reduction	By taking nitrogen fertilizer as an example, about 52% enters the environment to form non-point source pollution; 5% causes eutrophication of surface water through runoff, 2% causes nitrate enrichment in groundwater through leaching, 34% forms acid rain or greenhouse gas through nitrification and denitrification, and 11% volatilizes to cause air pollution	Maintain the current situation Chemical fertilizer reduction by 25% Chemical fertilizer application reduction by 50% Chemical fertilizer application reduction by 75%
Pesticide application reduction	The average pesticide application per mu in China is 2.5 times the world average level. According to the investigation, 10–20% of pesticides adhere to plants, 40–60% fall on soil and water, and 5–30% diffuse into the atmosphere	Maintain the current situation Pesticide application reduction by 25% Pesticide application reduction by 50% Pesticide application reduction by 75%
Agricultural waste recovery rate	Cultivated land waste mainly includes straw, chemical fertilizer, and pesticide package and agricultural film, etc. Incineration of waste will cause severe air pollution, and random disposal will cause soil hardening and water pollution and endanger the survival of animals and plants	All recovered in categories Maintain the current situation
Compensation amount	Compensation (RMB) is given to peasant households per mu every year when implementing the control mentioned above scheme	RMB 0, RMB 150, RMB 200, RMB 300, RMB 400, RMB 500 and RMB 600

TABLE 2 | Examples of selection cards in selecting experiment.

Attributes	Scheme 1	Scheme 2	Maintain the current situation
Chemical fertilizer application reduction	Maintain the current situation	Application reduction by 75%	Not participated
Pesticide application reduction	Application reduction by 25%	Maintain the current situation	Not participated
Agricultural waste recovery rate	All recovered in categories	Maintain the current situation	Not participated
Compensation (year/mu)	RMB 200	RMB 300	0

TABLE 3 | Descriptive analysis of sample characteristics.

Characteristics	Groups	Frequency	Percentage (%)
Sex	Male	208	87.39
	Female	30	12.61
Age	Under 35 years old	59	24.79
	35–60 years old	117	49.16
	60 years and above	62	26.05
Educational level	Primary school	78	32.77
	Junior high school	115	48.32
	Senior high school	44	18.49
	University or above	1	0.42
Source of household income	Farming	45	18.91
	Working	141	59.24
	Doing business	48	20.17
	Government relief	4	1.68
Annual household income	Less than RMB 10,000	49	20.59
	RMB 10,000–RMB 30,000	62	26.05
	RMB 30,000–RMB 50,000	69	28.99
	More than RMB 50,000	58	24.37

The coefficient of compensation is positive, indicating that compensation can effectively stimulate peasant households' willingness to participate in pollution control. The coefficient of reducing the application of chemical fertilizers and pesticides is positive, indicating that the losses brought to peasant households by reducing the application of chemical fertilizers and pesticides by 1% are 0.0068 and 0.0053, respectively. The coefficient of agricultural waste recovery is negative, and its variable is not significant, which may be caused by the large difference in peasant households' selection preference for waste recovery in actual production. The cross-term coefficients of ASC and head of household or not, years of education, degree of part-time farming, ecological benefits, degree of risk preference, and degree of understanding of policies and measures for non-point source pollution control of cultivated land are negative. The coefficient of the cross term with age and area of cultivated land is positive,

TABLE 4 | Empirical results of MNL model.

Variable	Model 1 basic model		Model 2 cross model	
	Coefficient	SD	Coefficient	SD
ASC	−2.337 3***	0.081 0	1.1383	0.8373
Compensation	0.001 6***	0.0002	0.0016***	0.0002
Chemical fertilizer application reduction	0.0068***	0.0010	0.0068***	0.0010
Pesticide application reduction	0.0053***	0.0012	0.0053***	0.0012
Agricultural waste recovery	−0.0588	0.0487	-0.0588	0.0487
ASC_Head of the household or not	—	—	−0.5414***	0.1839
ASC_Age	—	—	0.0292***	0.0097
ASC_Years of education	—	—	-0.0430*	0.0256
ASC_Area of cultivated land	—	—	0.0370**	0.0172
ASC_Degree of engaging in two or more undertakings	—	—	−0.3489***	0.1178
ASC_Ecological benefit	—	—	−0.2054**	0.0941
ASC_Health benefits	—	—	−0.1027	0.0965
ASC_Degree of risk preference	—	—	−0.709 6***	0.1256
ASC_Know about the policies and measures for non-point source pollution control of cultivated land or not	—	—	−0.6951***	0.0919
ASC_Know about ecological compensation or not	—	—	−0.016	0.089
Loglikelihood	−3 156.43	—	−3 063.62	—
Prob > chi2	0.00	—	0.00	—

, **, * represent significance levels of 10, 5, and 1%, respectively.*

TABLE 5 | Compensation standards for different restoration effects.

Compensation item	World average level		Organic production level	
	Attribute variation	Compensation standard (RMB/ hectare year)	Attribute variation	Compensation standard (RMB/ hectare·year)
Chemical fertilizer	Chemical fertilizer application reduction by 73%	4607.70	100% Chemical fertilizer application reduction by 100%	6311.85
Pesticides	Pesticide application reduction by 60%	2981.25	100% Pesticide application reduction by 100%	4968.75
Total	—	7588.95	—	11280.60

indicating that the younger, the higher the education level, the higher the degree of family part-time farming, the higher the recognition degree of the ecological function of non-point source pollution control of cultivated land, the higher the risk preference and the greater the willingness of heads of households with a better understanding of non-point source pollution control policies of cultivated land to participate in ecological compensation of non-point source pollution control of cultivated land. However, the larger the area of cultivated land, the more it will affect their willingness to participate in pollution control, which may be because peasant households are unwilling to change the current situation for their worries that the compensation is not enough to make up for their losses.

Calculation of Compensation Standard

Both ecological benefits and economic losses of peasant households shall be considered in the formulation of compensation standards. According to **Formula 10**, the marginal willingness of peasant households to be compensated for reducing the application of chemical fertilizers and pesticides by 1% is RMB 63.15/ha year and RMB 49.65/ha year. Ecological compensation standards with different restoration effects can be obtained from **Formula (11)**, as shown in **Table 5**.

Suppose the average input of chemical fertilizers and pesticides per mu in China is reduced to the world average level. In that case, the ecological compensation standard is RMB 7,588.95/(ha year), in which the application of chemical fertilizers and pesticides needs to be reduced by 73 and 60%. The compensation standards of the two are RMB 4,607.70/(ha year) and RMB 2,981.25/(ha year), respectively. Suppose the traditional production mode is restored to the organic production mode without applying any chemical fertilizers and pesticides. In that case, the ecological compensation standard is RMB 11,280.60/(ha year), in which the compensation standards for reducing the application of chemical fertilizers by 100% and pesticides by 100% are RMB 6,311.85/(ha year) and RMB 4,968.75/(ha year), respectively.

DISCUSSION

Problem Analysis

The risk of yield reduction and the shortage of technology are also the major issues that affect peasant households' interest to participate in non-point source pollution control (Huang et al., 2019; Arning et al., 2021). Regarding the question "Do you think your rice has been polluted?" the results are shown in

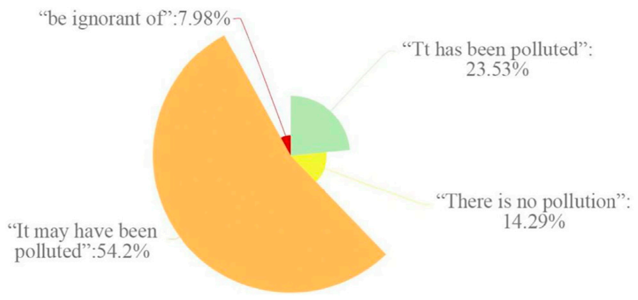

FIGURE 3 | Peasant households' cognition of non-point source pollution of cultivated land.

Figure 3, which shows that peasant households have a poor understanding of non-point source pollution of cultivated land. Therefore, in addition to financial compensation, in-kind compensation and technical compensation are added in this questionnaire to ask about peasant households' compensation preferences, with the results shown in **Figure 4**.

As can be seen from the above figure, for "water management", the compensation method selected by peasant households is mainly financial compensation, with a total of 217 households, accounting for 91.18%. For "lime application", 61 households select in-kind compensation, accounting for 25.63%; 39 households select "financial compensation", accounting for 16.39%; 138 households select "technical compensation", accounting for 57.98%. For "soil conditioner application", 113 households select in-kind compensation, accounting for 47.48%; 107 households select financial compensation, accounting for 44.96%; only 18 households select technical compensation, accounting for 7.56%. For "organic fertilizer application", peasant households mainly select financial compensation, with a total of 177 households, accounting for 74.37%; 53 households select in-kind compensation, accounting for 22.27%; only 8 households select technical compensation, accounting for 3.36%. For "green manure planting", the number of households selecting in-kind compensation and financial compensation is close, 104 households and 117 households, accounting for 43.70 and 49.16% respectively; 17 households select technical compensation, accounting for 7.14%.

According to the results, peasant households have different compensation modes for different ways of improving the cultivated land environment. Generally speaking, peasant households selecting in-kind compensation believe that the materials provided by the government are more time-saving and labor-saving, and the quality is guaranteed compared with those that they go to the market for selection by themselves (Lu et al., 2019c; Chen et al., 2021). However, peasant households who do not select in-kind compensation usually believe that in-kind compensation is lagging behind and fixed and cannot be adjusted flexibly. For peasant households selecting financial compensation, this method may be simpler and more direct, with great freedom, and coordination can be done according to their actual farming situation. Peasant households selecting technical compensation usually believe that they don't know the relevant knowledge of cultivated land management. However, they can learn and implement management measures through technical compensation provided by the government to improve the quality of their cultivated land and food.

Research Limitations

This paper mainly studies the compensation standard for non-point source pollution control of cultivated land in some counties and cities of Hunan Province. In order to promote the formulation of environmental protection compensation policies, further research can be carried out from the following two aspects due to the limitations of research methods and data: 1. There are significant differences between rural areas and peasant households. When formulating policies, the differentiation of compensation methods shall be appropriately

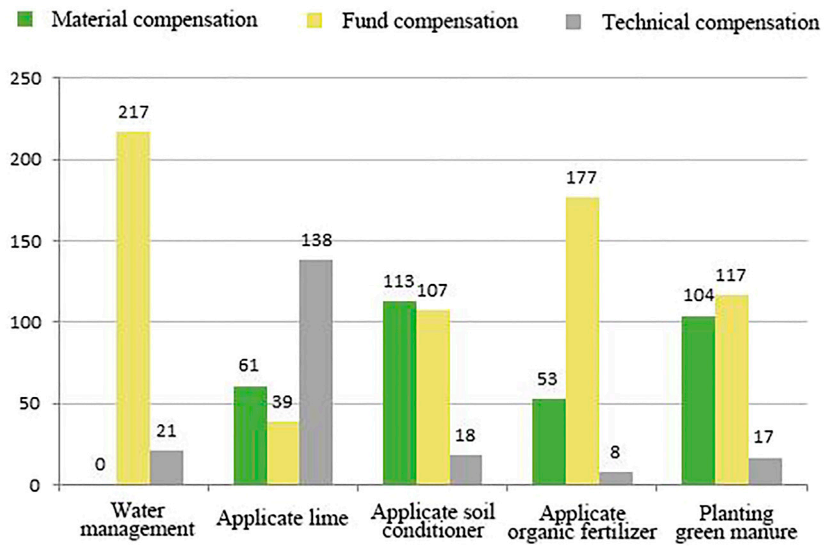

FIGURE 4 | Compensation mode preference.

considered, which shall start from the actual situation and vital interests of peasant households as far as possible to ensure the maximum benefit of ecological compensation. 2. There are also differences in crop production and economic development in different regions. General compensation standards that can be further popularized will be obtained in the follow-up research through benefit transfer and other methods.

CONCLUSION

In this paper, the ecological benefits are included in the compensation standard for non-point source pollution control of cultivated land by using the selection experiment method and calculated. From the research results, the following conclusions and policy recommendations can be drawn:

1. According to the results, financial compensation can effectively stimulate peasant households' willingness to participate in non-point source pollution control of cultivated land. The compensation standards for reducing the application of chemical fertilizers and pesticides by 1% are RMB 63.15/(ha year) and RMB 49.65/(ha year), respectively. Furthermore, the compensation standards for reducing the application of chemical fertilizers and pesticides in traditional production methods to the international average level and the organic production level are RMB 7,588.95/(ha year) and RMB 11,280.60/(ha year), respectively. The compensation standard is obtained by comprehensively considering the economic losses obtained by peasant households' participation in control and the ecosystem value. Therefore, peasant households' interest demands shall be considered when formulating ecological compensation policies. The economic losses and ecological benefits obtained by peasant households' participation in control shall be comprehensively considered.
2. Peasant households' socio-economic characteristics are quite different. Age, education level, and pollution awareness will have a significant impact on their willingness to be compensated. In addition to considering the actual situation of peasant households as much as possible when formulating policies, peasant households can also be educated on environmental protection through modern media to improve their subjective enthusiasm to participate in non-point source pollution control of cultivated land.
3. In addition to the source control method of reducing application and emission, methods such as lime application and green manure planting can also improve the cultivated land environment, thus the compensation method need not be limited to the financial compensation method. Peasant households' compensation preferences for different control measures are quite different. In addition to ecological benefits, the differentiation of compensation methods shall be incorporated into the design of compensation standards for non-point source pollution control of cultivated land, and ecological compensation policies shall be formulated according to local conditions to maximize the benefits of ecological compensation.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

Conceptualization, SL; Formal analysis, SL; Investigation, WZ; Methodology, WZ; Software, WL; Validation, FT-H; Writing – original draft, SL and WZ; Writing – review and editing, WL and FT-H. All authors have read and agreed to the published version of the manuscript.

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Can Industrial Agglomeration Facilitate Green Development? Evidence From China

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Industrial agglomeration can promote economic growth through knowledge spillover and cooperation, while it may also bring serious pollution problems. Therefore, clarifying the relationship between industrial agglomeration and green development is of great significance to the realization of China's sustainable development. In order to study the causal relationship between industrial agglomeration and green development, this paper first adopts the Overall Malquist Index method to more accurately measure the green development of Chinese cities characterized by environmental total factor productivity (ETFP). Subsequently, this paper uses the panel data of prefecture-level cities from 2003 to 2016 to study the causal relationship between industrial agglomeration and green development. We found that China's current industrial agglomeration can promote green development. Mechanism analysis shows that industrial agglomeration can promote green development through improving the technological innovation, strengthening government intervention and optimizing the industrial structure. Finally, heterogeneity analysis shows that industrial agglomeration has a stronger role in promoting green development in areas where the economy is more developed, the degree of resource dependence is lower, and the degree of industrial agglomeration is higher. This paper not only provides theoretical and policy references for the research on industrial agglomeration and green development, but also provides experience reference for other developing countries.

Keywords: industrial agglomeration, environmental total factor productivity, technological progress, government intervention, industrial structure, green development

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INTRODUCTION

In the more than 40 years since the reform and opening up, China's economy has continued to grow steadily and has achieved world-renowned achievements. However, China has long adopted an extensive economic growth model characterized by labor-intensive and resource-intensive production methods (Li et al., 2013), which has caused a lot of environmental pollution. According to the 2016 China Environmental Statistics Bulletin, the average $PM_{2.5}$ concentration in 338 cities across the country is 39 μg/m^3, which is far behind the World Health Organization (WHO) standard of 10 μg/m^3. Among them, it exceeds the ambient air quality limit. There are as many as 254 cities, and only 9.1% of the 5118 groundwater monitoring points in prefecture-level cities have good water quality. With the shortage of resources and rising labor prices, resource and environmental constraints have become more serious. Therefore, growing the environment total factor productivity has also become key to China's economic transformation and development. The report of the 19th National Congress of the Communist Party of China puts forward: "Take the supply-side structural reform as the main line, promote the quality of economic development, efficiency, and dynamics, grow total factor productivity, as well as promoting green development." Under the wave of sustainable development, growing environmental total factor productivity (ETFP) and finally realizing city green development has become a strategic need for China's sustainable economic development in the new era.

Industrial agglomeration reflects the spatial distribution characteristics of economic development, which is an important engine and growth pole to promote economic development. Meanwhile, industrial agglomeration refers to the economic phenomenon of large-scale aggregation of enterprises within a certain geographic space. There is a huge exchange of material and energy between enterprises and the surrounding environment during the process of industrial agglomeration, which improves the regional green development capacity and efficiency. As China enters a stage of high-quality development, economic development is gradually shifting from an extensive mode of pursuing growth speed to a mode of pursuing coordinated development between economic, social, and environmental benefits. The "13th Five-Year Plan" and "Made in China 2025" propose to accelerate the construction of ecological civilization and promote the development of green industries. The "Industrial Green Development Plan (2016-2020)" also proposes to improve the system and mechanism of agglomeration areas and the innovation of operation and management models, and to strengthen the comprehensive utilization of resources. Under the policy guidance of high-quality development, industrial agglomeration has also become one of the key factors in whether China can achieve green, sustainable and high-quality development.

There has been an abundance of research on the relevant theories of industrial agglomeration. Marshall externalities emphasize that industrial agglomeration has economies of scale (Dixit and Stiglitz, 1977) and various spillover effects (Fujita, 1989). The spatial concentration of elements is conducive to saving various costs and improving the efficiency of element use, thereby improving the utilization efficiency of energy and environmental elements. Glaser (2011) also pointed out through research that cities with high agglomeration are more energy-efficient and environmentally friendly than villages with low economic density. Second, the theory of Jacobs externalities puts forward the effect of diversified industry agglomeration, which mainly refers to the labor agglomeration effect, knowledge spillover effect, and the sharing effect of public infrastructure under the background of industrial diversification (Jacobs, 1969). Diversified agglomeration is conducive to strengthening the internal connections between enterprises and generating a benign green technology spillover effect, which is beneficial to the green development of cities. Finally, research related to new economic geography believes that technological externalities and technological spillovers between enterprises are the main driving forces of industrial agglomeration (Krugman, 1991), and the improvement of research and development efficiency of clean technology brought about by industrial agglomeration helps improvement of city environmental efficiency (Krugman, 1998).

Judging from the reality of China. For one thing, the eastern coastal areas with a high degree of industrial agglomeration have a higher level of economic development and relatively higher pollutant emissions, while the western areas with a relatively low degree of industrial agglomeration have the opposite. For another, as a key area of economic and trade outside the city, The China National Economic and Technological Development Zone is the main area of industrial agglomeration. So far, China has established 219 National Economic and Technological Development Zones. However, the scale of energy consumption and environmental pollution in these areas are also very serious. In view of the difference between theory and China's actual situation, does industrial agglomeration lead to increased city energy consumption and environmental damage, or dose it facilitate city green development and environmental efficiency? Obviously, this requires strict normative analysis and robust empirical testing to provide a scientific answer to this question. As China enters the stage of high-quality development, studying the impact of industrial agglomeration on green development has very important theoretical and practical significance for China's economic development goals and sustainable development. However, on the one hand, the existing literature needs to improve the accuracy of ETFP estimation at the city level (Afsharian and Ahn, 2015). On the other hand, there are few literatures that conduct rigorous empirical research on industrial agglomeration and green development at the city level in China.

In order to more accurately measure the ETFP at the city level in China, and conduct a rigorous empirical analysis of the causal relationship between industrial agglomeration and green development, this paper first adopts the Overall Malquist Index method proposed by Afsharian and Ahn (2015) to more accurately measure the green development of Chinese cities characterized by ETFP. Secondly, this paper uses the panel data of prefecture-level cities from 2003 to 2016 to study the causal relationship between industrial agglomeration and green development. We found that China's current industrial agglomeration can promote green development. Mechanism analysis shows that industrial agglomeration can promote green development through improving the technological innovation, strengthening government intervention and optimizing the industrial structure. Finally, heterogeneity analysis shows that industrial agglomeration has a stronger role in promoting green development in areas where the economy is more developed, the degree of resource dependence is lower, and the degree of industrial agglomeration is higher. This paper not only provides theoretical and policy references for the research on industrial agglomeration and green development, but also provides experience reference for other developing countries.

This paper contributes to the existing literature in the following ways. First, to our knowledge, this paper is among the first time to use the Overall Malquist Index method to make a more accurate measurement of ETFP at the prefecture city level in China. Traditional literature usually uses parameters, SBM, global and other methods to measure ETFP at the provincial level in China. There are problems such as model setting errors and inflated feasible regions, which eventually lead to large errors in the calculation of ETFP (Pastor and Lovell, 2005; Zhang and Ye, 2015; Tang et al., 2017; Xia and Xu, 2020; Lu et al., 2021). We used the method of Afsharian and Ahn (2015) to make a more accurate calculation of ETFP at the city level in China on the basis of correcting the feasible range.

Secondly, we also conducted a more comprehensive and in-depth analysis of the causal relationship between industrial agglomeration and green development. Guo et al. (2020) only discusses the impact of industrial agglomeration in Northeast China on the efficiency of green development. More documents have individually studied the effects of industrial agglomeration on pollution and economy (e.g., Liu and Zhang, 2021; Tanaka and Managi, 2021), or the influencing factors and calculation methods of ETFP(e.g., Hoang and Coelli, 2011; Fang et al., 2021). Few documents have strictly empirically proved the causal relationship between industrial agglomeration and green development. We not only rigorously proved the causal relationship between industrial agglomeration and green development, but also further analyzed the impact mechanism and heterogeneity.

The remainder of this paper is organized as follows. *Literature Review and Theoretical Mechanisms* outlines the literature reviews and theoretical mechanisms. *Methods and Data* explains our estimation strategy, econometric models, data and variables. *Empirical Results and Discussion* presents the empirical results. *Conclusion* concludes.

LITERATURE REVIEW AND THEORETICAL MECHANISMS

Industrial Agglomeration and Environmental Total Factor Productivity

ETFP is also called green total factor productivity, eco-efficiency or green development efficiency, it measured the efficiency of production, which refers to generating more output with less input (capital, labor, energy) while emitting less pollution. The literature on ETFP mainly includes two aspects, namely the calculation of ETFP and the analysis of ETFP influencing factors. The literature for measuring ETFP mainly uses parametric and non-parametric methods, and calculates ETFP from the provincial level or the enterprise level. For example, Chen et al. (2016) used the analytic hierarchy process (AHP) and constructed an evaluation index system for China's industrial green development. Feng et al. (2017) used a hybrid model and window analysis to measure the efficiency of China's regional industrial green transformation. Li et al. (2016) used data envelopment analysis (DEA) to evaluate the sustainable development of resource-based cities. Cheng and Li (2018) used non-directional distance function (NDDF) and the meta-Frontier method to measure the green growth of China's manufacturing industry. Hu et al. (2019) used ultra-relaxation Super-Slack Based Measure (SBM) function and the Global Malmquist-Luenberger (GML) index to calculate the environment total factor productivity of China's manufacturing.

Other document mainly studies the constituent elements and influencing factors of ETFP. The literature related to this research mainly focuses on the impact of input-output factors, technological progress, and government regulations on ETFP. The literature's research conclusions on the influence of input-output factors are relatively consistent, and they believed that factors such as resources and environment have a significant impact on ETFP. For example, excessive use of energy and excessive emissions of SO_2, CO_2, and COD are the main sources of environmental inefficiency (He et al., 2016), and the regional economic development level and ETFP show a strong positive correlation (Zhang and Ye, 2015). He et al. (2016) also found through specific calculations that provinces with higher environmental efficiency are concentrated in the eastern economically developed regions, while the overall ETFP growth level in the central and western regions is relatively low. Xia and Xu (2020) found through further research that the decrease in the output value of the secondary industry with high energy consumption and high pollution and the increase in the output value of the tertiary industry can effectively promote the growth of ETFP.

In terms of the impact of technological progress, Liu and Xin (2019) used provinces in the "One Belt, One Road" strategy as the research object and found that technological progress is the main reason for the increase in ETFP. Yan et al. (2020) further studied the technological innovation level of renewable energy at the provincial level and found that only after the urban economy has developed to a certain stage, technological progress can significantly promote the growth of ETFP. Feng et al. (2018) conducted a detailed analysis of China's metallurgical industry and found that technological progress is the most important factor in promoting the growth of ETFP. Wang et al. (2020) further studied 34 industrial sectors in China and found that technological innovation is the main driving factor for the growth of ETFP. Part of the literature also analyzed from the perspective of enterprise R and D investment. For example, Chen and Golley (2014) conducted a study on 38 industrial sectors in China and found that R and D investment intensity has a significant role in promoting ETFP, while Xia and Xu (2020) found through further research that the higher the proportion of R and D investment in GDP, the more it can promote the growth of ETFP.

The literature on the research conclusions on the effect of government intervention is quite divergent. He et al. (2016) believe that the government's environmental management capacity and ETFP show a negative correlation; Zhang and Jiang (2019) found through empirical research that the ETFP of key environmental protection cities in China is lower than that of non-key protection cities, while the Porter Effect of government environmental regulations still exists. Compared with "command-and-control" environmental regulatory policies, market-based environmental regulatory policies can exert a greater Porter Effect and have a greater role in promoting ETFP (Xie et al., 2017). Wang et al. (2019) found through further research that government environmental regulation can significantly promote the growth of ETFP under appropriate intensity, but excessive environmental regulation will offset the innovation effect, thereby inhibiting

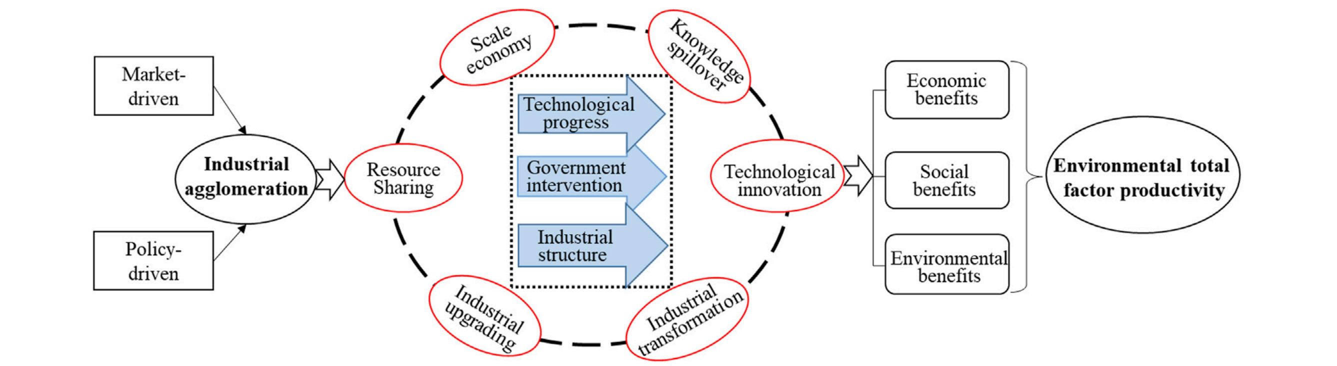

FIGURE 1 | Mechanism of industrial agglomeration influencing environmental total factor productivity.

ETFP. Liu et al. (2018) also found an inverted U-shaped relationship between the intensity of government environmental regulations and environmental efficiency. Jin et al. (2020) and Song et al. (2018) found an inverted U-shaped relationship in the relationship between the intensity of intergovernmental competition, fiscal decentralization, and ETFP.

In the literature related to the influence of industrial agglomeration on ETFP, Chang and Oxley (2009) found that industrial agglomeration can promote ETFP through innovation spillover. Cheng and Jin (2020) found that the industrial complementarity in industrial agglomeration has the strongest promotion effect on ETFP. Lu et al. (2021) believes that the common agglomeration of producer services and manufacturing has significantly promoted the improvement of regional GTFP and has a positive spatial spillover effect on surrounding areas. Xie et al. (2019) thought that the professional agglomeration of producer services not only increases the GTFP of cities and surrounding cities, but also weakens the promotion of GTFP in cities and surrounding cities by the professional agglomeration of producer services. Guo et al. (2020) studied the industrial agglomeration and green development efficiency in Northeast China, found that there is a u-shaped relationship between them, and analyzed the impact of economic development, environmental regulation, and other factors on ETFP.

Mechanism Analysis

This paper uses the industry clusters as the carrier to explore the facilitation of China's industrial agglomeration on the ETFP in prefecture-level cities. Three paths have been constructed: technological innovation, government intervention and industrial structure. It may be through economies of scale, knowledge spillover effects, technological innovation effects, industrial upgrading effects, industrial transformation effects, and resource sharing effects on city economic performance, social performance, and environmental performance. Thereby accelerating environmental innovation, improving energy efficiency, and promoting the improvement of the production efficiency of city environmental total factors. The specific mechanism diagram (**Figure 1**) and the mechanism analysis are as follows.

First, industrial agglomeration has a positive impact on innovation through the Marshall externalities agglomerated within the industry (Arrow, 1971; Romer, 1986). Practitioners through face-to-face technical exchanges and information interactions in agglomeration areas are conducive to the spillover of environmental protection knowledge and green technology among enterprises. Second, industrial agglomeration is conducive to the interaction, sharing, and diffusion of energy-saving information and clean technology among enterprises (Wang et al., 2021; Xie et al., 2019). At the same time, cross-industry agglomeration activities are conducive to promoting the deep integration of information and communication technologies such as the Internet and big data with industrial industries, thereby promoting technological innovation. For example, Baptista and Swann (1998) found that the British manufacturing industry has a higher level of agglomeration and a higher level of innovation. In addition, industrial agglomeration strengthens the degree of competition among enterprises. Industrial agglomeration encourages enterprises not only to carry out technological and process innovation but also to learn from each other in the fields of knowledge and technology, thereby giving birth to new ideas and knowledge, accelerating the progress of low-carbon and environmentally friendly technologies, and increasing the green productivity of the industry. In summary, through the spillover effects of clean technology and knowledge, industrial agglomeration is conducive to improving the level of regional technological progress (especially the promotion of environmentally friendly innovative technologies), which can increase the ETFP (Xie et al., 2020). Therefore, this paper proposes the following hypothesis:

Hypothesis 1: Industrial agglomeration could grow the ETFP through the improvement of technological level.

Second, industrial agglomeration can influence ETFP through government intervention. The increase in production efficiency brought about by industrial agglomeration has significantly improved the income and living standards of residents, as well as the ecological and environmental problems that have begun to become prominent. Therefore, the government will raise environmental standards for industrial production, driving industrial agglomeration to gradually transform into green ecological agglomeration. Government intervention is mainly through the formulation of relevant laws and regulations, environmental subsidies, and other means to achieve city governance to facilitate pollution control (Ghazouani et al., 2021; Song et al., 2019). On the one hand, environmental regulations are considered to be the most effective way to solve environmental pollution. The government establishes an active intervention and supervision mechanism by formulating a series of corresponding environmental protection policies and regulations. For example, the government uses fines and shuts down high-polluting enterprises to increase the cost of environmental pollution by enterprises (Guo and Wang, 2018), thereby improving environmental pollution (Shen and Wang, 2018). On the other hand, the government encourages enterprises to introduce advanced production technologies through direct financial compensation for the R and D and application of green technology innovations in enterprises (Cheng et al., 2017), thereby enabling enterprises in agglomeration areas to achieve a "win-win" (Porter and Linde, 1995). In summary, this paper proposes the following hypothesis:

Hypothesis 2: Industrial agglomeration can facilitate the growth of ETFP by strengthening government intervention.

Third, industrial agglomeration can promote ETFP by optimizing the industrial structure. Economic structure and economic activities can have an important impact on environmental pollution and carbon emissions (Ikram et al., 2021; Sharma et al., 2021), and further affect environmental sustainability (Rafique et al., 2021). industrial agglomeration causes enterprises to obtain innovation monopoly profits, and various departments will compete to increase R and D investment to improve production efficiency and production technology level, thereby promoting the adjustment of industrial structure from the supply side. At the same time, industrial diversification and agglomeration optimize the structure of input factors through horizontal and vertical cooperation between industrial chains, thereby promoting the optimization and upgrading of industrial structure. Optimizing the industrial structure can reduce energy consumption (Yu et al., 2018) and reduce pollutant emissions (Cole et al., 2005), thus promoting the improvement of ETFP. Based on this, this paper proposes the following hypothesis:

Hypothesis 3: Industrial agglomeration is conducive to the optimization and upgrading of the industrial structure, thereby promoting ETFP.

METHODS AND DATA

Methods

In order to study the causal effect between industrial agglomeration and ETFP, we set up the following model based on the method of Lin et al. (2011), Li et al. (2021), Hu et al. (2015) and Liu and Zhang (2021):

$$ETFP_{it} = \alpha_0 + \alpha_1 Agg_{it} + \alpha_2 X_{it} + \beta_1 \gamma_i + \beta_2 \sigma_t + \varepsilon_{it} \tag{1}$$

where i represents city, t represents year, $ETFP$ represents the environmental total factor productivity growth, Agg represents the degree of industrial agglomeration, X represents control variables, γ_i represents city fixed effect, σ_t represents year fixed effect, andε_{it} represents the random error term.

Variables and Data

Dependent Variable

The current measurement methods for ETFP mainly include parameter methods and non-parametric method represented by data envelope. Compared with parametric methods, data envelopment analysis does not need to set the function form and put forward various hypotheses. At the same time, it can also build in weights through the optimization method according to the characteristics of the data itself, which can avoid the interference of people's subjective will to the greatest extent possible. In the data envelopment analysis method, the Malmquist total factor productivity index analysis method can analysis the changes in productivity, technical efficiency, and technological progress on panel data containing multiple time points. It was not until Pastor and Lovell (2005) proposed the global reference Malmquist index that the four assumptions were met simultaneously. The global reference Malmquist index is based on the sum of each period as the reference set, namely

$$PPS^G = convex\{PPS^1 \cup \ldots \cup PPS^T\} \tag{2}$$

where T represents each period and PPS^T represents the production feasible set during T period. PPS^G represents the production feasible set constituted by the convex combination of input-output observation values in all periods. However, Afsharian and Ahn (2015) think that since the external conditions of T in different periods are not completely consistent, it is unreasonable to form the overall production feasible set by a convex combination of arbitrary inter-period input and output. Furthermore, the production feasible set needs to meet an implicit condition in the construction process, that is, the technology of any T period within the feasible set is unchanged.

Taking **Figure 2** as an example, the subscripts 1 and 2 respectively represent two periods that occur in sequence. The points in period 1 form the front surface of $OA_1B_1C_1$, and the points in period 2 form the front surface of OA_2B_2. The global reference proposed by Pastor and Lovell (2005) is to combine the points of all periods to form a Frontier, which is $OA_1A_2B_1C_1$ in **Figure 1**. However, Afsharian and Ahn (2015) posited that the technological Frontier of the global reference violates the underlying assumption that the same Frontier technology remains unchanged. For example, in the global reference, both A_1 and A_2 are on the leading edge. However, due to the different periods, the technologies of A_1 and A_2 are also different. Therefore, it is impossible to construct the same front surface with both. Forced construction will inflate the real production feasible set (such as A_1A_2M and A_2B_1N), which will lead to bias in efficiency calculations.

To solve the problem of efficiency bias caused by the inflated production feasible set, and to avoid the problem of no feasible solution for inter-period DDF, we refer to the practice of

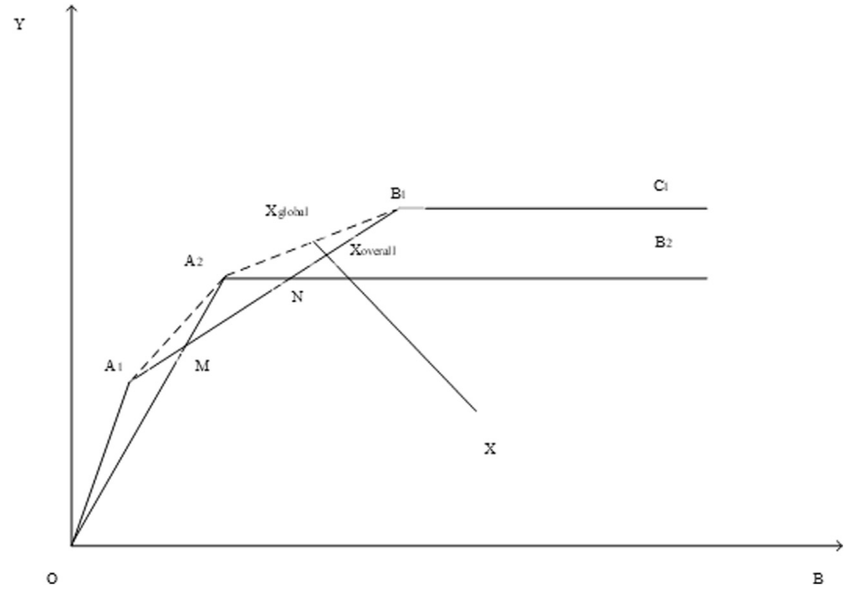

FIGURE 2 | Global PPS and overall PPS.

Afsharian and Ahn (2015), and improved on the basis of Pastor and Lovell (2005). We define the overall production feasible set under environmental constraints as:

$$PPS^o = PPS^1 \cup \ldots \cup PPS^T \tag{3}$$

where T represents each period and PPS^o represents the union of production feasible sets in all periods. The production feasible set is calibrated from $OA_1A_2B_1C_1$ to $O_1A_1MA_2NB_1C_1$, eliminating the two production infeasible parts of A_1A_2M and A_1B_1N. Under the definition of global reference in **Figure 2**, the projection of point X on the technological Frontier is X_{global} on A_2B_1, which is not on the production feasible set. After calibrating the production feasible set, its projection on the technological Frontier surface is the $X_{overall}$ point on the B_1N, which excludes the infeasible part of production in any period, makes the PPS conform to the actual experience, and eliminates the bias in the process of calculating the efficiency value.

Under the constraints of the overall production feasible set in this part, and combined with the approach of Zhou et al. (2012), the non-angle and non-radial DDF based on the overall technology under environmental constraints is defined as:

$$\vec{D}^o(x, y, b; g) = \sup\{W^T\beta: (x, y, b) + g \times diag(\beta) \in P^o(x)\} \tag{4}$$

where $W = (w^x, w^y, w^b)^T$ represents the weight vector of input, expected output, and undesired output, respectively, and g is the direction vector. We set $g = (g_x, g_y, -g_b)$ to indicate that the desired direction of efficiency improvement is input reduction, expected output increase, and undesired output decrease. $\beta = (\beta_x, \beta_y, \beta_b)^T \geq 0$ represents the proportionality factor, and its value is the possible ratio of input reduction, expected output expansion, and undesired output reduction, and represents the measured inefficiency value. The inefficiency value of the non-angle and non-radial DDF in period t based on the overall technological Frontier can be obtained by solving the following linear programming model:

$$\begin{aligned} \max \quad & \beta \\ s.t. \quad & X\lambda + \beta x_k \leq x_k \\ & Y\lambda - \beta y_k \geq y_k \\ & B\lambda + \beta b_k \leq b_k \\ & \lambda \geq 0 \\ & \textstyle\sum \lambda = 1 \end{aligned} \tag{5}$$

where β is the inefficiency value solved by non-angle and non-radial DDF, λ is the coefficient, and the sum is 1, which means that this paper assumes that the return to scale is variable. X, Y, and B represent the vectors of input, expected output, and undesired output[1], respectively.

Under the DEA framework, the environmental TFP growth index is calculated based on environmental efficiency. The most common forms are Malmquist-Luenberger productivity index and Luenberger productivity index. Among them, the Malmquist-Luenberger productivity index is a ratio form, usually combined with the radial efficiency measurement model, while the additive form of Luenberger productivity is more compatible with the non-radial efficiency measurement model that is, also an additive form (Zhang and Choi, 2014). According to the Luenberger productivity index form, based on

[1]Input factors include labor (expressed by the total number of employees in the three industries), capital (expressed by total fixed asset investment), and energy consumption (expressed by annual electricity consumption). Expected output is expressed by GDP, and undesired output includes industrial wastewater discharge and industrial SO_2 emissions

the overall PPS and non-angle and non-radial DDF, the environmental TFP growth (ETFP) between period t and t + 1 is defined as:

$$ETFP = \vec{D}^{O}\left(x^{t}, y^{t}, b^{t}; g^{t}\right) - \vec{D}^{O}\left(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1}\right) \quad (6)$$

In general, the advantage of the Overall Malmquist Index method proposed by Afsharian and Ahn (2015) for ETFP calculation is that this method corrects the problem of false increase in the feasible range compared with the traditional calculation method, so that ETFP can be more accurately calculated (Jia et al., 2021; Xu et al., 2021; Zhao et al., 2018; Zhu et al., 2021).

Independent Variable

Agglomeration can be understood as the relative concentration of a certain element in a region. Common indicators used in existing studies to measure the degree of agglomeration of economic variables include Herfindahl index, Gini index, location entropy index, and Ellision-Glaeser index (Kamal and Sundaram, 2019). Among them, Herfindahl index, Gini index, and Ellision-Glaeser index can only measure the degree of agglomeration of elements at a global level but cannot effectively observe the degree of agglomeration of elements within each region, so they are not suitable for this study. The location entropy index can measure the spatial distribution of elements in a certain area, and is suitable as an effective index to measure the spatial distribution and agglomeration level of the research object, and it is comparable between different geographical units within the area (O'Donoghue and Gleave, 2004), so as to meet the needs of this research. Therefore, we draw on the idea of location entropy index and follow the method of Liu et al. (2021) and Mo et al. (2020) to construct the ratio of city secondary industry employees to the national secondary industry employees. This industry agglomeration index measures the degree of industrial agglomeration in each city, and its specific calculation formula is as follows:

$$Agg_{it} = \frac{emp\_\mathrm{sec}_{it}/emp_{it}}{\sum_{i=1}^{N} emp\_\mathrm{sec}_{it} / \sum_{i=1}^{N} emp_{it}} \quad (7)$$

where emp_sec_{it} represents the number of employees in the secondary industry in city i in year t, and emp_{it} represents the total number of employees in the primary, secondary and tertiary industries in city i in year t.

Mechanism Variables

(1) Technological progress (Tec). Regional industrial gatherings have a significant impact on the level of technological progress, and industrial gatherings produce knowledge and technology spillover effects, which are conducive to the integration of innovative elements, saving innovation costs, and improving innovation performance to facilitate regional technological innovation (Amiti, 2005). We use the number of patents related to green innovation in each prefecture-level city to indicate the level of technological progress in the region.

(2) Government intervention (Gov). Industrial agglomeration will also affect government intervention in industries to a certain extent. As industrial agglomeration facilitates the continuous expansion of production scale, this may cause problems such as over-utilization of resources and environmental pollution, forcing the government to adopt relevant legal regulations and subsidies to improve resource efficiency and alleviate environmental pollution and other issues (Shen and Wang, 2018). We measure the degree of government intervention by using the ratio of fiscal expenditure to the city's GDP after deducting education and science.

(3) Industrial structure (Ins). On the one hand, industrial agglomeration reduces enterprise costs through economies of scale (Venables, 1996). On the other hand, it also provides pressure and motivation for enterprise technological innovation. Therefore, industrial agglomeration is an important driving force for the optimization and upgrading of the regional industrial structure. We use the ratio of the number of employees in the secondary industry to the number of employees in the tertiary industry to express.

Control Variables

(1) Foreign direct investment (Fdi). Existing research has two main views on the impact of foreign direct investment on environmental pollution: the "pollution refuge" hypothesis holds that foreign direct investment increases environmental pollution in the host country (Cole et al., 2005). The "pollution halo" hypothesis (Balsalobre-Lorente et al., 2019) pointed out that the adoption of standardized management and production technologies by foreign-funded enterprises can help promote the construction of environmental management systems by domestic enterprises through spillover effects, and this would produce a pollution halo effect and improves environmental quality. Therefore, the sign of the coefficient of foreign direct investment is uncertain. Without loss of generality, we use the proportion of foreign direct investment in the city's GDP to measure it.

(2) Population density (Pop). Population density reflects the growth rate of economic development and the agglomeration level of regional alliances, and its impact on industrial pollution agglomeration is unclear. On the one hand, areas with higher population densities usually have more frequent economic activities, which may generate more pollution emissions (Li et al., 2019). On the other hand, human capital is a key driving force for sustainable economic growth. The higher the population density, the higher the level of human capital, which may be beneficial to energy conservation and emission reduction (Shao et al., 2011). Without loss of generality, we use the population per square kilometers to measure it.

(3) Weather factors. Meteorological factors can directly affect the undesired output of economic activities. For example, the occurrence of temperature inversion can alleviate air pollution (Jans et al., 2018; Sager, 2019). Wind speed, rainfall, temperature, etc. can also affect the concentration of air pollutants such as $PM_{2.5}$. Therefore, to more accurately

TABLE 1 | Descriptive statistics.

Variables	Obs	Mean	S.D	Min	Max
ETFP	3,718	0.0035	0.0612	−0.517	0.4980
Agg	4,031	0.9410	0.3030	0.0934	1.9090
Ins	4,031	0.9680	0.6360	0.0470	5.4840
Pop	4,031	0.0420	0.0317	0.0011	0.2230
Gov	4,032	0.1300	0.1060	0.0281	2.1920
Tec	4,698	2930.0	9519.0	1.0000	165906
Fdi	3,938	0.0029	0.0032	−0.013	0.0454
Tem	4,671	14.360	5.5480	−2.200	27.880
Hum	4,671	66.490	10.800	29.000	91.000
Pre	4,613	944.50	551.60	36.500	2711.0
Sun	4,655	2046.0	550.20	247.00	3673.0

TABLE 2 | Baseline regression.

Variables	ETFP				
	(1)	(2)	(3)	(4)	(5)
Agg	0.0147	−0.0140	0.1094***	0.1521**	0.1144***
	(0.0138)	(0.0096)	(0.0379)	(0.0552)	(0.0384)
Control variables	YES	NO	YES	NO	YES
Weather variables	YES	NO	NO	YES	YES
City FE	NO	YES	YES	YES	YES
Year FE	NO	YES	YES	YES	YES
Constant	0.0123	−0.0019	−0.0813*	−0.2003*	−0.1346
	(0.0238)	(0.0106)	(0.0407)	(0.1066)	(0.1059)
Adjusted R^2	0.0001	0.0859	0.0985	0.0973	0.0961
Observations	3555	3717	3624	3608	3555
Cities	280	288	283	282	280

*Note: The significance levels of 1, 5, and 10% are denoted by ***, **, and *, respectively. Robust standard errors are reported in parentheses.*

measure the impact of industrial agglomeration on ETFP, we further controlled meteorological factors including temperature (Tem), humidity (Hum), precipitation (Pre), and sunshine (Sun).

(4) Descriptive statistics of data. Based on the selection of the above variables, we have performed descriptive statistics on the data, and the results are reported in **Table 1**. Among them, the meteorological data comes from the China Meteorological Administration, and the patent data comes from the query of the patent cloud database. The remaining variables are from the China City Statistical Yearbook.

EMPIRICAL RESULTS AND DISCUSSION

Baseline Results

First, we use the baseline regression in **Table 2** to study causal relationship between industrial agglomeration and ETFP. Column (1) reports the results of POOL-OLS. We find that the impact of industrial agglomeration on ETFP is not significant without considering the fixed effects of cities and time. Columns (2) to (5) further control multiple effects. Specifically, column (2) controls city fixed effects and year fixed effects based on column (1). Columns (3) and (4) control macroeconomic variables and meteorological factors on the basis of the column (2), respectively. Column (5) controls macroeconomic variables, meteorological factors, city fixed effects, and year fixed effects.

We can find from column (5) that, after considering all control variables and fixed effects, industrial agglomeration can significantly facilitate ETFP. Specifically, on average, for each additional industrial agglomeration (10.63%), the ETFP increases by 11.44% (3.32%). This corresponds to an elasticity between industrial agglomeration and ETFP of 31.23%. Also, we can convert the magnitude using standard deviations. The estimates indicate that a one standard deviation increase in industrial agglomeration increases ETFP by 0.023 standard deviations.

TABLE 3 | Mechanism test.

Variables	Tec	Gov	Ins
	(1)	(2)	(3)
Agg	0.4796**	0.0385***	1.9595***
	(0.2274)	(0.0112)	(0.2286)
Control variables	YES	YES	YES
Weather variables	YES	YES	YES
City FE	YES	YES	YES
Year FE	YES	YES	YES
Constant	3.8543***	0.0778	−1.0313***
	(1.0881)	(0.0784)	(0.2333)
Adjusted R^2	0.8666	0.4019	0.6830
Observations	3847	3847	3847
Cities	283	283	283

*Note: The significance levels of 1, 5, and 10% are denoted by ***, **, and *, respectively. Robust standard errors are reported inparentheses.*

Mechanism Analysis

We investigated the three mechanisms of industrial agglomeration affecting ETFP, and **Table 3** reports the estimated results. Column (1) shows the impact of industrial agglomeration on technological innovation. We find that industrial agglomeration can significantly facilitate regional technological innovation levels related to green development. Specifically, due to the knowledge spillover effect that exists in the process of industrial agglomeration, industrial agglomeration can increase the level of technological innovation by 47.96% at the 5% significance level. Industrial agglomeration strengthens the upstream and downstream linkages of industries, which is conducive to enhancing input-output linkages, expanding knowledge spillover effects, and improving the availability of human capital, thereby reducing the cost of technological knowledge dissemination, generating technological innovation effects, improving the level of green technological innovation, and promoting ETFP. This research conclusions is consistent with Guo et al. (2021), who found that green innovation and CO_2 are cointegrated, and green innovation is one of the key contributors in explaining CO_2 emissions.

Column (2) reports the impact of industrial agglomeration on government intervention. We can find that industrial agglomeration can significantly facilitate the degree of local government intervention, thereby achieving an increase in ETFP. This is inseparable from the Chinese

TABLE 4 | Robustness test.

Variables	Replace ETFP	Delete capital city	Delete heavily polluted areas	Delete eastern region
	(1)	(2)	(3)	(4)
Agg	0.1122**	0.1220***	0.1179***	0.1056**
	(0.0457)	(0.0395)	(0.0400)	(0.0458)
Control variables	YES	YES	YES	YES
Weather variables	YES	YES	YES	YES
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Constant	−0.1341	−0.1395	−0.1559	−0.1149
	(0.1130)	(0.1202)	(0.1112)	(0.1270)
Adjusted R^2	0.1209	0.1115	0.0949	0.1012
Observations	3568	3174	3208	2448
Cities	281	250	253	194

*Note: The significance levels of 1, 5, and 10% are denoted by ***, **, and *, respectively. Robust standard errors are reported in parentheses.*

government's continued attention to environmental and ecological issues in recent years. In terms of environmental investment, the government has continuously strengthened its investment in pollution control and increased its investment in green technology research and development for enterprises in concentrated areas. In terms of system construction, the government has continuously improved environmental regulations in agglomeration areas and improved relevant laws and regulations, fully implemented the pollution discharge permit system in agglomeration areas, and continued to facilitate market-oriented transactions such as pollution rights, energy rights, water rights, and carbon emissions rights, thereby promoting the city environment improvement of total factor production efficiency. This conclusion is also in line with Farooq et al. (2019) and Shahzad (2020). The burning of fossil fuels causes the emission of greenhouse gases and environmental pollutants, which in turn leads to environmental degradation and affects health. The strengthening of government environmental regulations such as environmental taxes (Farooq et al., 2019) and afforestation (Shahzad, 2020) will reduce environmental pollution and improve environmental quality.

Column (3) shows the impact of industrial agglomeration on the industrial structure. We can find that the improvement of industrial agglomeration can significantly facilitate the upgrading of industrial structure. More companies have transitioned from the secondary industry to the tertiary industry and further improved the regional ETFP. This may be caused by the following reasons. On the one hand, the increase in industrial agglomeration has strengthened the degree of market competition among enterprises, forcing enterprises to continuously improve technology and update equipment to gain competitive advantages, thereby achieving regional industrial structure upgrades. On the other hand, industrial diversification and agglomeration contribute to the formation of the entire industrial chain, improve the production efficiency of the manufacturing industry, and realize the upgrading of China's manufacturing industry to the high-end of the global value chain. At the same time, it facilitates the vigorous development of the tertiary industry such as productive services. Finally, the ETFP is improved. Similar to the conclusion of Doğan et al. (2021) that economic complexity can alleviate environmental degradation, in the process of promoting the optimization and upgrading of industrial structure, industrial agglomeration has also promoted the growth of labor force, the improvement of production technology and the use of clean energy to a certain extent, thereby promoting the growth of ETFP.

Robustness Test

To make our results more credible, we have conducted a large number of robustness tests through a variety of methods. The results are shown in **Table 4**. First, the undesired output in the ETFP calculation process includes the 3-year moving average data of the $PM_{2.5}$ of China's prefecture-level cities calculated by Columbia University using satellites. We replaced the relevant $PM_{2.5}$ concentration data with the annual $PM_{2.5}$ concentration data calculated by the atmospheric composition analysis group of Dalhousie University in Canada. We find from column (1) that, after replacing the calculation content of ETFP, industrial agglomeration can still facilitate ETFP at the 5% significance level.

As China's prefecture-level cities or provincial capital cities are the facades of this region, the effects of any national policies must be first shown in provincial capital cities. This also caused the provincial government to concentrate all political resources in the provincial capital to ensure that the provincial capital can fulfil the relevant national policy requirements. If this kind of government behavior is not eliminated, it will cause an overestimation of the effect of industrial agglomeration on ETFP. Therefore, we exclude four municipalities and all provincial capital cities, and the regression results are reported in column (2). We can find that after excluding government behaviors in provincial capital cities, industrial agglomeration can still facilitate ETFP at the 5% significance level.

Second, China has implemented transformational development in recent years, and more environmental policies have further strengthened the regulation of environmental pollutant emissions. The Chinese government has implemented the strictest environmental regulations and policies for the "2 + 26" cities with

TABLE 5 | Heterogeneity test.

Variables	Industrial concentration		Area			City type	
	High	Low	East	Central	Western	Resource-based	Non-resource
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Agg	0.2508***	0.1014*	0.1317**	0.1339	0.0876	0.1164*	0.1166**
	(0.0749)	(0.0590)	(0.0570)	(0.0807)	(0.0561)	(0.0571)	(0.0481)
Control variables	YES	YES	YES	YES	YES	YES	YES
Weather variables	YES	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES
Constant	−0.2252	−0.1248	−0.2085	−0.1591	−0.0130	−0.1672	−0.1122
	(0.1969)	(0.1590)	(0.1790)	(0.1212)	(0.1510)	(0.1892)	(0.0970)
Adjusted R^2	0.1084	0.0963	0.0839	0.1573	0.0784	0.1060	0.0905
Observations	1757	1798	1107	1008	1440	1345	2210
Cities	186	196	86	78	116	106	174

*Note: The significance levels of 1, 5, and 10% are denoted by ***, **, and *, respectively. Robust standard errors are reported in parentheses.*

the most serious environmental pollution. Strict environmental regulation policies can significantly improve regional air quality. If these 28 regions are not excluded, we cannot distinguish the role of environmental regulation policies and overestimate the impact of industrial agglomeration on ETFP. Column (3) reports the estimated results after excluding 28 areas with serious environmental pollution. We can find that after excluding the impact of environmental regulatory policies, industrial agglomeration can still facilitate ETFP at the 1% significance level.

Finally, since the sample time of this paper started in 2003, it includes the migration of polluting enterprises from the east to the west in the Western Development Policy. The development of the secondary industry in the eastern region has been saturated, while the western region has a large amount of resources needed for the development of manufacturing enterprises. With the implementation of the western development policy, enterprises with serious pollution in the eastern region have moved to the western region. This caused an overestimation of the effects of industrial agglomeration policies in the eastern region. Column (4) excludes the heavy industrial areas in the east to excludes the influence of the western development policy. We can find that industrial agglomeration can still increase ETFP at the 5% significance level.

Heterogeneity Analysis

We also conducted a heterogeneous analysis of three aspects of the impact of industrial agglomeration on ETFP in **Table 5**. First, we rank the industrial agglomeration of all cities each year. We estimate the areas where the industrial agglomeration is higher than the average and lower than the average, respectively, to see the impact of different level of agglomerations on ETFP. We find from columns (1) and (2) of **Table 5** that regions with high industrial agglomeration can significantly facilitate ETFP at the 1% significance level, while regions with low agglomeration have no significant effect on promoting ETFP.

Further, we separately examined the impact of industrial agglomeration in the eastern, central, and western regions on ETFP. From columns (3) to (5), it can be found that industrial agglomeration in the eastern region can have a significant impact on ETFP at the 5% significance level, while industrial agglomeration in the central and western regions has no significant impact on ETFP.

Finally, we examine the heterogeneity between resource-based cities[2] and non-resource-based cities. The reason for the agglomeration of industries in resource-based cities may be to get closer to the geographical location of local mineral resources. The industrial agglomeration of non-resource-based cities can not only reduce the cost between the upstream and downstream of the industrial chain but also produce the Porter effect and achieve technology spillover, thereby improving production technology and achieving higher-quality development. Therefore, the impact of industrial agglomeration on ETFP will vary with city types. Columns 6) and 7) report the estimated results. We find that in non-resource-based cities, industrial agglomeration can indeed facilitate the increase of ETFP at the 5% significance level, while this facilitation effect is not significant in resource-based cities.

CONCLUSION

Based on the panel data of 283 cities in China from 2003 to 2016, this paper first adopts the Overall Malquist Index method proposed by Afsharian and Ahn (2015) to more accurately measure the green development of Chinese cities characterized by ETFP. Subsequently, this paper study the causal relationship between industrial agglomeration and green development. We found that China's current industrial agglomeration can promote green development. On average, for each additional industrial agglomeration (10.63%), the ETFP increases by 11.44% (3.32%). This corresponds to an elasticity between industrial

[2]According to the plan for the sustainable development of resource-based cities in China (2013–2020) issued by the State Council: resource-based cities are cities in which the mining and processing of natural resources such as minerals and forests in the region are the leading industries (including prefecture-level cities, districts and other county-level administrative districts, etc.). There are a total of 262 resource-based cities, including 126 prefecture-level administrative regions, 62 county-level cities, 58 counties, and 16 municipal districts. Available online at: http://www.gov.cn/zwgk/2013-12/03/content _2540 070.htm

agglomeration and ETFP of 31.23%. Mechanism analysis shows that industrial agglomeration can promote green development through improving the technological innovation, strengthening government intervention, and optimizing the industrial structure. Finally, heterogeneity analysis shows that industrial agglomeration has a stronger role in promoting green development in areas where the economy is more developed, the degree of resource dependence is lower, and the degree of industrial agglomeration is higher.

Our policy recommendations are as follows. First, under the background of the new dual-cycle development pattern, the government should use agglomeration areas as carriers to accelerate industrial agglomeration and industrial chain upgrading. On the one hand, local construction should be guided by green development and gradually introduce new and green industrial construction policies. The government should develop the environmental protection industry, promote the green transformation of key industries and important fields, and promote the safe and efficient use of clean, low-carbon energy. On the other hand, the government should encourage and introduce new enterprises, strengthen legal and policy guarantees for green development, promote cleaner production, support industrial enterprises to increase R&D investment, promote technological innovation and the transformation of scientific and technological achievements, and strengthen advanced production technologies, especially low-carbon technologies and energy saving. In addition, the government should strengthen the innovation of the system and mechanism, supporting facilities, and operation and management models in the industrial cluster areas, and strengthen the efficiency of the comprehensive utilization of resources. Meanwhile, policymakers should expand the regional boundaries of interaction between agglomeration industries, build a long-term mechanism for the coordinated development of industrial agglomerations sharing knowledge, technology, and information, as well as promote the sustainable development of regional integration.

Second, it is necessary to strengthen the coordination and linkage mechanism of government intervention in industrial agglomeration. On the one hand, the government should encourage enterprises to carry out technological innovation. For industries with higher innovation output and high production efficiency, preferential policies such as fiscal subsidies and tax reductions and exemptions should be given to improve the efficiency of green innovation. On the other hand, under the strengthening of the system of environmental regulation, the government should improve the construction of the intellectual property protection system, to form an oppressive mechanism for enterprise innovation. Meanwhile, the government should encourage green technological innovation and management system innovation to open up space for cross-border integration of innovative elements such as talent, information, knowledge, and technology in the modern industrial system. In addition, relying on the knowledge spillover effect between industries agglomerated, and through innovative elements such as "technology + finance" and "Internet +," promote green financial innovation represented by the carbon financial market, and help market incentives such as carbon emissions trading and emissions trading. The design and improvement of environmental regulatory policy tools will facilitate the growth of city ETFP.

Third, the government should formulate corresponding industrial agglomeration development policies according to different economic development levels and city types. First, for cities in the eastern region with a high level of economic development, while continuously optimising industrial policies, we will formulate strict environmental regulations, continue to promote green technology research, green smart manufacturing, and modern energy technology applications, and strive to create a modern, green development industrial agglomeration. For cities in the central and western regions, development should be their primary goal. Decision-makers should flexibly use environmental regulatory policies and industrial policies, strengthen the leading role of regional core cities, as well as promote the positive externalities of industrial agglomeration, to realise the coordinated development of urban economy and environment. Second, due to resource-based cities' environment and resource constraints, they should focus on accelerating changes in growth patterns, promote the optimization of the industrial structure in agglomeration areas, eliminate outdated industries, and actively introduce advanced green technologies and management methods to achieve faster reduction of pollutants emission.

There are some limitations in this paper. First, although we include the main input, expected output, and undesired output variables in the calculation of ETFP, due to data limitations, we have no way to obtain other undesired output variables. Second, in the mechanism analysis, some channels were not fully reflected. For example, mechanism variables such as the improvement of labor skills and the improvement of corporate management efficiency can also promote the growth of ETFP, but we do not have enough data to disentangle them. One suggestion for future research is to design, administer, and survey with more detailed macroeconomic variables and micro individual variables information to examine their role in ETFP.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

WX: Conceptualisation, Formal analysis, Investigation, Writing—original draft, XL: Methodology, Writing—review and editing, Supervision, Funding acquisition.

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Assessing Energy Efficiency for Economic and Sustainable Development in the Region of European Union Countries

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The objective of this research is to estimate the energy-saving intensities of nations within the European Union, applying varied equations of the DEA analysis, such as the DEA, modified radial equation, Russel dynamic envelope analysis, and the adjusted Russel Dynamic envelope Analysis, throughout the period of 2010–2018. Unlike other studies, this analysis seeks to unravel whether European nations are effective in increasing the EE finance of their respective economies. Because the European Union not only has geographical ties between regions, it is also a collection of interests of various sovereign states, its energy exhibits efficiency changes under the relationship of competition and cooperation under that economic effect. Regarding this circumstance, different dynamic envelope evaluations were formulated. One primary finding is that nations such as Germany, Sweden, or Austria attain robust ecological safeguard performance, seem to be using less energy, and are ecologically efficient relative to other nations such as Denmark, Belgium, Spain, France, or Ireland. Furthermore, a group of Eastern EU nations attained reduced efficiency marks, which could be categorized as anticipated, as a result of reduced technological implementation within the principal manufacturing sectors. The main result of this study is that few nations are performing in terms of efficiency. Additionally, RE (Renewable Energy) power production expands as nations' dynamic envelope analysis marks and creates inefficient governments nearer to the efficiency frontline. Inversely, the presence of peak-time power consumption reduced the dynamic envelope analysis marks and increased the distance from the Frontier of efficiency (the optimal value of efficiency).

Keywords: financial development, data envelopment analysis, European Union, energy efficiency, assessment

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INTRODUCTION

The European Union's economic policy and development strategy aim to create a low carbon economy as well as a resource-efficient economy. To realize this goal, the European Union aims to grow its efficiency in terms of energy consumption by about 20 percent, decrease carbon dioxide emissions to 20 percent of the cumulative energy being consumed, and generate 20 percent of its energy from Renewable Energies (RES). This initiative is called the 20–20-20 plan of action by the EU (Nugent and Rhinard 2019). The primary energy consumption sectors of the European Member states are anticipated to play an important part in the realization of this plan of action. In many instances, agricultural activities tend to focus on ecological destruction, in the form of the misapplication of energy resources, high-level carbon dioxide pollution, and the overutilization of nitrogen fertilizer. (Jungmeier 2017). In order to meet the United Kingdom's climate change goals of 80 percent household carbon cuts by 2050 from the reference year 1990, the United Kingdom's housing units need reconstruction or refitting to make them energy saving. During previous years, retrofit policy programs aimed at ensuring these standards were being met in buildings, for example through loft lining. The disparity amongst the energy savings attained as well as the possibility of energy cutbacks led to a significant shortfall in efficiency standards in the United Kingdom's real estate market (Jurgita Malinauskaite et al., 2020).

Energy Efficiency (EE) has faced a lot of impediments among stakeholders in the form of information asymmetry, as well as technical, financial, institutional, and lifestyle disparity. This information asymmetry presents market distortion and shortfalls that are challenging to overcome (Alemzero et al., 2021), (J. Malinauskaite et al., 2019). Notwithstanding important commitments concerning the advancement of the community in fast-tracking energy efficiency expansion, the findings are very modest. Excluding the agglomeration of bankable projects, service providers and investors seem adamant to venture into the market (Dunlop 2019). The process of ascertaining how varied energy efficiency undertakings are structured, portrayed, funded, and executed in an efficient and cost-effective way is also challenging. Bankable undertakings are, however, cumbersome to pinpoint and formulate as the project is not backed by market players. This means that consumers often buy old appliances, meaning that suppliers presume that consumers are conservative and that they do not want energy-saving appliances. These impediments to project successes are endemic in emerging nations, as discussed by Acquah (2021) and Economidou et al. (2020).

Studies on EE according to dynamic envelope analysis have been published in diverse scholarly journals around the world (König et al., 2020). Relying on data from web science, numerous research has been published using the DEA approach. As such, a full assessment and synopsis of literature on this area is required (Palm and Backman 2020). The key aim of this study is to examine the present condition in addition to emerging indicators of EE centered on the dynamic envelope analysis. This study differs from past research in that it reviews studies on this subject area, whereas past ones studied only limited aspects of this subject (Sueyoshi et al., 2017). Furthermore, different from other research, which depends on the subjective knowledge of the authors, the actual findings are derived from real data evaluation, which is more impartial. (Mardani et al., 2017).

Within the past 20 years, the dynamic envelope analysis approach has attained greater popularity within the fields of energy and ecological efficiency approximation of nations, along with the provincial stages (Sueyoshi and Goto 2017), (Chen and Gong 2017), and (Yu and He 2020). China's regional pollution and efficiency evaluation has assumed prominence in current years due to its size as the most significant carbon dioxide emitter by volume in the world. There exist several scholarly works on China applying the dynamic envelope analysis, see for example (Mohd Chachuli et al., 2020), (Singpai and Wu 2021) and (Guo et al., 2020). Their works are centered on various time phases, provinces, areas, key-ins, and productivity items, and apply various dynamic envelope analysis equations that result in problems in drawing parallels concerning their findings. (Meng et al., 2019).

Even so, the research (Xu et al., 2020) talks about several hurdles concerning the dynamic envelope analysis for energy as well as ecological examination. Thus, there is no complete overview of the utilization of the dynamic envelope analysis equations to estimate provincial efficiency, taking into account diverse parameters. Hence, this study estimates a methodical overview of the empirical analysis done in recent times on China's provincial energy and CO2 pollution efficiency evaluation, applying the dynamic envelope analysis (Meng et al., 2019) and (Moon and Min 2020).

The principal findings of the analysis are listed below: 1) The collation of the characteristics of past research that are crucial for scholars to comprehend previous advancement as well the future trajectories within this field of research. 2) Providing a necessary point of reference for dynamic envelope analysis equation choice within the viewpoint of methodological as well as scientific findings. 3) We produce similar findings for various dynamic envelope analysis equations, applying comparisons. 4) The evaluation of differences in the EE of the European Union. The primary reason for the analysis is assessing the features of EE according to research on dynamic envelope analysis and giving a point of reference for further research and study. The above points connote the critical findings of the research to the field of scholarly works on the subject area via providing additional pragmatic findings to draw comparison alongside advancing the course of EE.

The rest of the paper is structured thus: Section two gives the methodological approach and past works applied within the analysis. Section three demonstrates the findings and discusses the results. Section four gives a detailed analysis of the knowledge spillover pathway analysis, andsection five concludes the study.

LITERATURE REVIEW AND BACKGROUND

Current studies have paid major attention to EE estimation approaches and approximates indexes. However, (Ouyang and Yang 2020), applied a qualitative approach to investigate various energy policies and estimates from Brazil, China, India, Mexico, alongside other nations, and discovered that policy can be crafted to spur energy consumption decreases separate from advancing EE. (Amowine et al., 2020), in finding the apparent provincial variations in EE, apply a parametric met Frontier approach to evaluate EE in the commercial sector of China.

More so, there were a few instances where the gross domestic product was applied to be the anticipated productivity, as the ecological emissions productivity was disregarded. The incremental factor EE estimation approaches are nonetheless pretty well known within past research. (Atta Mills et al., 2021) utilized the dynamic envelope analysis equation to estimate the EE of the six sectors with the most effective energy use within the United States, excluding the ecological limitations. The study discovered that the pulp and paper industry attained the biggest EE. Furthermore, there are scholarly works that consider the anticipated productivity when estimating the EE. (M. L. Song M.-L. et al., 2013) put in the ecological restraint to the dynamic envelope analysis equation, estimated to the total factor EE of the Yangtze River Delta metropolitan area, and examined the parameters that influence the EE expansion percentage. (Y. He et al., 2018) included the ecological restraints in their analysis to the equation drawn to compare the EE of energy concentrated companies within China. Integrating past studies synopsizes, our study utilizes the computation approach of the total factor for EE, bearing in mind the unwanted productivity, plus did a relative analysis on whether or not to include the ecological restraints on EE.

Similarly, there are rationally two kinds of dynamic envelope analysis equation. The first one is called CCR-DEA (Charnes et al., 1978) and BCC-DEA (Banker et al., 1984), which could be modified and radially anchored on all key-ins. CCR is applied to estimate the total efficiency according to constant returns to scale, and together with BCC is utilized to estimate pure technology plus the effectiveness centered on variables returns to scale (VRS). Then, the second is the slack-based measure model, which carries non-radial slacks into account and likewise decreases the mistakes in estimation occasioned by choosing radially. Again, we apply the approaches of (Zhang et al., 2021) and (Li et al., 2021) besides integrating the benefits of CCR-DEA and SBM-DEA, formulating an Epsilon-based Measure (EBM-DEA) equation to estimate the EE of the organization of economic cooperation and development between nations, and also excluding the unwanted productivity (Mardani et al., 2017), (K. Wang et al., 2013), (Cui and Li 2015) and (L. W. Wang et al., 2019).

The choice of the key-ins besides the productivity parameters indicates how the dynamic envelope analysis equation is near to actual circumstance and influences the figures of the comparative efficiency of decision-making units. Because the dynamic envelope analysis has a robust correlation alongside production theory, the crude material, and resources applied within the generation procedures are ordinarily categorized as key-ins and increase productivity. Overall, the dynamic envelope analysis increases key-ins plus increases productivity. Nevertheless, when unwanted productivity is added, the dynamic envelope analysis has to increase the desirable productivity and concurrently minimize the unwanted productivity (P. He et al., 2019) of the key-ins together with productivity parameters applied in past research. Regarding the key-ins parameters, the labor force, capital stock, and cumulative energy consumption are the critical parameters applied in past studies. Specifically, the labor force was utilized in over 90 percent of the research. Concerning the productivity parameters, gross domestic product and carbon dioxide are the chosen parameters between the wanted and unwanted productivity, respectively.

DATA AND ECONOMETRIC MODEL

Energy Efficiency Through Radial Model

The dynamic envelope equation is additionally considered as the dynamic envelope analysis type that returns to the scale of the baseline year technology. According to this overview, six kinds of the dynamic envelope analysis equations have been used in China's provincial energy efficiency and CR estimates; to name a few, the Radial model, Modified-Radial Model (M-Radial), Russell Measure Model (RMM), Tone's Slack Based Model (SBMT), Range Adjusted Model g (RAM), and the Directional Distance Function Model (DDF). (Iftikhar et al., 2018) depicts the equation in addition to these sources. These equations could be categorized regarding the comparative modification perhaps not Key-ins, as well as productivity, are proportionally modified regarding the radial equation. The remaining equations discussed within are the non-radial equations. Within them, the SBMT and RAM equations are slack-centered estimate approaches due to the fact that they formulate efficiency indicators explicitly within the slacks in the keys-ins as well as productivity. The granularity concerning the properties and the construction of these equations are deliberated in the subsequent section. Here, the dynamic envelope analysis equations explained in (Yang and Wei 2019) are statistically elucidated. Now, take into account the generation process alongside K decision-making units (DMUs) that changes non-energy key-ins plus energy key-ins 5) to generate productivity (y). Microeconomic theory elucidates the generation technology T to be:

$$T = \{(X, e, Y):\ (x, e) can\ produce\ Y\}$$

$$\text{Min } \beta$$

$$T(x, e, y) = \sum_{k-1}^{K} \lambda_k x_{nk}$$

$$\le x_{n0}\ (n = 1, \ldots\ldots N)$$

$$\sum_{k-1}^{K} \lambda_k e_{mk}$$

$$\le \beta e_{m0}$$

$$(m = 1, \ldots\ldots M)$$

$$\sum_{k-1}^{K} \lambda_k y_{ik}$$

$$\ge\ y_{i0} = (i = 1, \ldots\ldots .I)$$

$$\sum_{k-1}^{K} \lambda_k b_{jk}$$

$$= \boldsymbol{b}_{j0} \quad (\boldsymbol{j} = 1, \ldots\ldots ..\boldsymbol{J})$$

$$\boldsymbol{\lambda_k} \ge 0$$

$$(\boldsymbol{K} = 1, \ldots\ldots ..\boldsymbol{K})$$

$$\boldsymbol{EE} = \boldsymbol{\beta}^*$$

where T depicts the elucidated baseline technology that is closed as well as restrictively set. In the baseline technology T, the key-ins plus the productivity are presumed to robustly one i.e. if (x, e, y) ∊ T and (x′, e′) ⩾ (x, e) (or y′ ⩽ y), then (x′, e′, y)∊T (or (x, e, y′) ∈ T). A distribution-free equation is normally applied to illustrate the baseline technology to practice what the concept prescribes. Assume there are N non-energy key-ins, M energy inputs, and I undesirable outputs, then $x_k = (x_{1k}, x_{2k}, \ldots, x_{Nk})$, $e_k = (e_{1k}, e_{2k}, \ldots, e_{Mk})$, yk = (y1k,y2k, … ,yIk). Hence, the baseline technology T could be reconstructed as a dynamic envelope analysis (Ouyang and Yang 2020). Likewise, the Radial equation, which modifies the key-ins in addition to the productivity equivalently, is perhaps the most widely applied model within this field. The widely acclaimed radial equations are the CCR equation plus the BCC equation. The reference RTS type technology set is their significant difference. The energy efficiency in addition to CE could be explained by applying the input-oriented as well as the unwanted productivity equations, correspondingly.

Energy Efficiency Through Modified Radial Mod

The returns to scale in economics depict the changes in productivity when the key-ins vary in proportion alongside other circumstances holding constant (Liu et al., 2021). Within the dynamic envelope analysis, returns to scale indicate the baseline technology, plus determine the form of the production frontline. Overall, there exist four kinds of returns to scale. Namely, statics returns to scale, non-increasing returns to scale, and changing returns to scale. (Imdadul Haque 2019) depicts the variations between these four kinds of return-to-scale types. Also, returns to scale are considered static when an equivalent expansion in all key-ins leads to the same equivalent expansion in productivity. On the other hand, if that results in a greater than equal, or below the equivalent expansion, in the productivity, the returns to scale are growing or regrowing. Static returns to scale are more widely applied in returns to scale analysis in past research. (Grösche 2009) illustrates that nearly 70 percent of the research is presumed to be constant returns to scale reference technology. Nearly twenty percent of research applied static returns to scale, varying returns scale, plus non-increasing returns to scale reference technologies together. The scale efficiency and the returns to scale properties of various decision-making units could be examined within this scenario.

$$\text{Min } \beta$$
$$s.t. \sum_{k-1}^{K} \lambda_k x_{nk} \le x_{n0}$$
$$\le x_{n0} \ (n = 1, \ldots \ldots N)$$
$$\sum_{k-1}^{K} \lambda_k e_{mk} \le e_{m0}$$
$$\le \beta e_{m0}$$
$$(m = 1, \ldots \ldots M)$$
$$\sum_{k-1}^{K} \lambda_k y_{ik} \ge y_{i0}$$
$$\ge y_{i0} = (i = 1, \ldots \ldots .I)$$
$$\sum_{k-1}^{K} \lambda_k b_{jk} = \beta b_{j0}$$
$$= \boldsymbol{b}_{j0} \quad (\boldsymbol{j} = 1, \ldots \ldots .. \boldsymbol{J})$$
$$\boldsymbol{\lambda_k} \ge 0$$
$$(\boldsymbol{K} = 1, \ldots \ldots .. \boldsymbol{K})$$
$$\boldsymbol{CE} = \boldsymbol{\beta}^{*}$$

The M-radial equation tries to estimate the efficiency by formulating an indicator that applies radial indicators plus the slacks together. This is thought to be a modified type of radial equation alongside key-ins plus productivity slacks. Here, the energy efficiency estimated from the M-radial equation is equally called the cumulative factor energy efficiency. The CE for M -radial model did not exist in (Mohsin et al., 2021) due to the fact that according to the ecological dynamic envelope analysis technology where unwanted productivity is 7 days disposable, as well as the slacks for unwanted productivity, are equivalent to zero.

Slack Adjusted Modified Radial Model

Alongside increasing ecological challenges, many studies have coupled ecological pollution as unwanted productivity in the manufacturing process onto the reference technology T. The widely acclaimed means to include wanted and unwanted productivity together is to set dual presumptions. There is weak disposability on productivity, i.e. if (x, e, y, b) ∈ T′ and 0 ⩽ θ ⩽ 1, then (x, e, θy, θb) ∈ T′. That implies that proportional cuts in wanted, as well as unwanted productivity, are probable, whilst it might not be possible to singly cut unwanted productivity. The null-joint output is made up of undesirable and desirable outputs., i.e. if (x,e,y,b) ∈ T′ and b = 0, then y = 0. That means unwanted productivity needs to be generated so as to produce wanted productivity. Equally, the single means to remove the unwanted productivity is to stop the manufacturing process. Here b=(b1, b2, … ,bJ) depicts the vector of undesirable productivity plus a T′ denoting the reference technology adding unwanted productivity. In reference to the aforementioned presumptions, T' could be categorized as,

$$Min$$
$$[\beta - \epsilon \ (e^T s_n^- + e^T s_m^- + e^T S_i^+)]$$
$$s.t. \sum_{k-1}^{K} \lambda_k x_{nk}$$
$$-s_i^+ = \beta x_{n0}$$
$$(n = 1, \ldots \ldots N)$$
$$\sum_{k-1}^{K} \lambda_k e_{mk}$$
$$-s_m^+ = \beta x_{m0}$$
$$(m = 1, \ldots \ldots M)$$
$$\sum_{k-1}^{K} \lambda_k y_{ik}$$
$$-s_i^+ = y_{i0}$$
$$(i = 1, \ldots \ldots .I)$$
$$\sum_{k-1}^{K} \lambda_k b_{jk}$$
$$= \boldsymbol{b}_{j0} \quad (\boldsymbol{j} = 1, \ldots \ldots .. \boldsymbol{J})$$
$$\lambda_k \ge 0;$$

$$s_n^- s_m^- S_i^+ \geq 0$$
$$(\boldsymbol{K} = 1, \ldots\ldots..\boldsymbol{K})$$
$$EE = \sum_{m-1}^{M} \varpi m \frac{\beta^* e_{m0} - s_m^{-*}}{e_{m0}}$$

The SBMT (Mehmood et al., 2020) equation and the RAM equation are both in the class of slack-based estimation, i.e., they formulate the efficiency indicator alongside the key-ins and productivity. As shown in (M. Song et al., 2013b), because the SBMT equation encompasses all inefficiencies for the inputs and the output, its explanation ability is more significant. The RAM equation could be measured as an additive equation that makes room for parameters to be next to zero.

Energy Efficiency Through Russell Measure Model (RMM)

Bearing in mind the vast presence of probable technical efficiency estimates in the dynamic envelope analysis, meeting particular properties from a statistical and economic viewpoint plays a crucial part in choosing one of them in performance. Regarding this purpose, the approximation efficiency of each decision-making unit, considering all types of technical inefficiency, has gained traction among scholarly works in the dynamic envelope analysis. (Alcaraz et al., 2021).

$$Min \sum_{m-1}^{M} \varpi_m \beta_m$$
$$s.t. \sum_{k-1}^{K} \lambda_k x_{nk} \leq x_{n0}$$
$$(n = 1, \ldots\ldots N)$$
$$\sum_{k-1}^{k} \lambda_k e_{mk}$$
$$\leq \beta_m e_{m0}$$
$$(m = 1, \ldots\ldots M)$$
$$\sum_{k-1}^{K} \lambda_k y_{ik} \geq y_{i0}$$
$$(i = 1, \ldots\ldots.I)$$
$$\sum_{k-1}^{k} \lambda_k b_{jk} = b_{j0}$$
$$(\boldsymbol{j} = 1, \ldots\ldots.. \boldsymbol{J})$$
$$\lambda_k \geq 0$$
$$(k = 1, \ldots\ldots.K)$$
$$EE = \sum_{m-1}^{M} \varpi_m \beta_m^*$$

Energy Efficiency Through Russell Measure Model (RMM)

The DEA is a distribution-free data-driven method to estimate the homogenous performance of enterprises that generates a category of productivity concerning a group of key-ins according to similar technological know-how. The dynamic envelope analysis equations rely on mathematical programming for ascertaining, concurrently, applying a multiple function straight-line equation for approximating the production frontline of the principal technology, the efficiency marks of the assessed components, and ultimately vital benchmarking information. Indeed, dynamic envelope analysis has been widely used in producing enterprises (Esmaeili 2012) and (Salahi et al., 2019).

$$Min \sum_{j-1}^{J} \varpi_j \beta_j$$
$$s.t. \sum_{k-1}^{k} \lambda_k x_{nk} \leq x_{n0}$$
$$(n = 1, \ldots\ldots N)$$
$$\sum_{k-1}^{K} \lambda_k e_{mk} \leq e_{m0}$$
$$(m = 1, \ldots\ldots M)$$
$$\sum_{k-1}^{K} \lambda_k y_{ik} \geq y_{i0}$$
$$(i = 1, \ldots\ldots.I)$$
$$\sum_{k-1}^{K} \lambda_k b_{jk} = b_{j0}$$
$$(\boldsymbol{j} = 1, \ldots\ldots.. \boldsymbol{J})$$
$$\lambda_k \geq 0$$
$$(k = 1, \ldots\ldots.K)$$
$$CE = \sum_{j-1}^{J} \varpi_j \beta_j^*$$

Alongside increasing ecological challenges, many studies have coupled ecological pollution as unwanted productivity in the manufacturing process onto the reference technology T. The widely acclaimed means to include wanted and unwanted productivity together is to set dual presumptions. There is weak disposability on productivity, i.e. if (x, e, y, b) ∈ T′ and 0 ⩽ θ ⩽ 1, then (x, e, θy, θb) ∈ T′. That implies that proportional cuts in wanted, as well as unwanted productivity, are probable, whilst it might not be possible to singly cut unwanted productivity. The null-joint output is made up of undesirable and desirable outputs., i.e. if (x, e, y, b)∈T′ and b = 0, then y = 0. That means unwanted productivity need to be generated so as to produce wanted productivity. Equally, to single means to remove the unwanted productivity is to stop the manufacturing process. Here b = (b1, b2, . . . ,bJ) depicts the vector of undesirable productivity plus a T′ denoting the reference technology adding unwanted productivity. In reference to the aforementioned presumptions, T′ could be categorized as,

$$Min \sum_{m-1}^{M} \varpi_m \beta_m$$
$$s.t. \sum_{k-1}^{k} \lambda_k x_{nk} \leq x_{n0}$$
$$(n = 1, \ldots\ldots N)$$
$$\sum_{k-1}^{K} \lambda_k e_{mk}$$
$$\leq \beta_m e_{m0}$$
$$(m = 1, \ldots\ldots M)$$
$$\sum_{k-1}^{K} \lambda_k y_{ik} \geq y_{i0}$$
$$(i = 1, \ldots\ldots.I)$$
$$\sum_{k-1}^{K} \lambda_k b_{jk} = b_{j0}$$
$$(\boldsymbol{j} = 1, \ldots\ldots.. \boldsymbol{J})$$

$$\lambda_k \geq 0$$
$$(k = 1, \ldots\ldots. K)$$
$$EE = \sum_{m-1}^{M} \varpi_m \beta_m^*$$
$$Min \sum_{j-1}^{J} \varpi_j \beta_j$$
$$s.t. \sum_{k-1}^{K} \lambda_k x_{nk} \leq x_{n0}$$
$$(n = 1, \ldots\ldots N)$$
$$\sum_{k-1}^{K} \lambda_k e_{mk} \leq e_{m0}$$
$$(m = 1, \ldots\ldots M)$$
$$\sum_{k-1}^{K} \lambda_k y_{ik} \geq y_{i0}$$
$$(i = 1, \ldots\ldots. I)$$
$$\sum_{k-1}^{K} \lambda_k b_{jk} = b_{j0}$$
$$(\boldsymbol{j} = 1, \ldots\ldots.. \boldsymbol{J})$$
$$\lambda_k \geq 0$$
$$(k = 1, \ldots\ldots. K)$$
$$CE = \sum_{j-1}^{J} \varpi_j \beta_j^*$$

Data Sources

We ascribe the data types deployed in this research, **section 3.1** analyses alongside the sustainability index incorporated in the dynamic envelope analysis and the Effmixf equations, and **section 3.2** alongside data needs for the energy system equations. The data was sourced from the following sources: the EU's Commission report, the IEA, and the WDI.

RESULTS AND DISCUSSION

Energy Efficiency

Here, the total of the expansion rate of technology is given as (g), capita; deprecation is rate (δ), and the expansion rate of the inhabited population is (n), denoting capita successful deprecation rate. The capital depreciation rate (δ) is assumed to be similar and static throughout the regions as well as for human and physical capital. It is presumed that to be equal to three percent per annum or fifteen percent in 5 years, according to MRW 1992. The resident population expansion rate is the only unit for the efficient deprecation of capital that changes via regions and within the course of time (n).

Table 1 shows the energy efficiency score. Technical efficiency is far from being attained by the European Union by 2020. It is crucial to stress that when the mean basis considers the efficiencies levels, bearing in mind that this research implements productivity-based dynamic envelope analysis, it means within the last 11 years. For example, productivity can grow to 47.28 percent while keeping similar key-ins. Also, 52.7 percent, 49.55 percent, and 51.15 percent represent the technical levels for the initial 3 years of 2010, 2011, and 2013. Within the same period, the mean marks indicate a trajectory of 57.55 percent, 77.35 percent, 77.16 percent, 83.78 percent, and 88.93 percent around 2013, 2014, 2015, 2016, 2017, and 2018, correspondingly. Additionally, the mean figures of a single nation of the period examined were estimated for the European Union, emphasizing the nations given in the study. Different colors depict the efficiency figures for every nation. The red denotes the minor efficiency marks, and blue depicts the mean scores, and the green shows the maximum efficiency marks derived. That generates a puzzle within the economic system of advanced nations, on the one hand; while on the different hand, it is an elucidation of relative poverty and lack of development. External jobs mean farm laborers earn extra wages, thus reducing poverty levels in rural settings. The other reason being, economic advancement makes urban dwellers earn higher incomes than those who live in rural areas, increasing the urban-rural income divide when economic system activity expands.

Table 2 shows the average energy efficiency score. Because a single energy key or unwanted productivity is included in the study, the RMM equation attains the Radial equation. As a result of the lack of space, only China's provincial energy efficiency and CE figures are anchored on varied equations. The analysis discovered three principal findings: 1) Within the models exists a noticeable disparity in the type of data used, showing each equation possesses an explanatory ability, strongor weak. 2) The models vary according to their efficiency levels. For instance, regarding EE figures changes regarding the equation choice. For instance, the energy efficiency computed by the Radial, M-radial, RMM, and RAM equations is more significant than those estimated by the SBMT equations. Concerning the efficiency of carbon pollution, statistics obtained from the RAM equation are more significant than others. 3) These equations might be grouped into two or three types due to the changing trend of efficiency statistics across the countries. Similarly, expanded earnings signify that the public has extra funding for countryside fiscal expenditure to eradicate or decrease the incidence of poverty. It is not surprising to detect that the European Union economic advancement attains the effect or gains of advancing poverty reduction efficiency. As a result, the effects of the European Union's economic advancement on reducing the incidence of poverty are still to be corroborated. The gross domestic product, gross domestic products per head, and the real gross domestic per head are generally applied within scholarly works to estimate the amount of economic expansion. Within the scenario, gross domestic product and actual gross domestic product per head are primarily observed in data evolution. Because the research places economic expansion as the control parameter, the gross domestic product is applied to estimate economic expansion.

Energy Efficiency Through Slack Based DEA Model

Bearing in mind table three, there exist essential clues for significant variations of energy and ecological efficiency execution of energy policy, according to EE. To be able to verify this, the slack-focused dynamic envelope analysis equation was executed. The initial result admits that EE has not been varied substantially after implementing the novel disintegration subsidy program of the EC, plus the following

TABLE 1 | Energy efficiency from 2010 to 2018.

Counties	2010	2011	2012	2013	2014	2015	2016	2017	2018
Denmark	1.00	1.00	0.98	0.86	0.86	0.84	0.86	0.86	0.86
Spain	1.00	1.00	0.98	0.98	0.98	0.86	0.84	0.86	0.98
Netherlands	0.47	0.51	0.45	0.47	0.50	0.52	0.52	0.50	0.47
Italy	0.37	0.41	0.42	0.43	0.44	0.45	0.45	0.44	0.47
Belgium	0.98	0.98	1.00	0.86	0.86	0.84	0.86	1.00	1.00
Bulgaria	0.65	0.61	0.64	0.67	0.79	0.79	0.67	0.67	0.62
France	0.45	0.44	0.47	0.43	0.44	0.45	0.47	0.47	0.50
Romania	0.45	0.47	0.47	0.49	0.50	0.47	0.50	0.47	0.54
Ireland	0.67	0.65	0.62	0.67	0.64	0.60	0.67	0.64	0.67
Luxembourg	0.42	0.43	0.44	0.45	0.45	0.47	0.47	0.50	0.50
Hungary	0.60	0.62	0.60	0.60	0.57	0.55	0.51	0.53	0.51
United Kingdom	0.51	0.52	0.50	0.50	0.55	0.49	0.45	0.47	0.47
Portugal	0.52	0.53	0.54	0.55	0.55	0.57	0.57	0.57	0.60
Greece	0.60	0.62	0.64	0.65	0.64	0.62	0.60	0.57	0.61
Germany	0.50	0.53	0.47	0.47	0.47	0.49	0.50	0.55	0.52
Estonia	0.60	0.61	0.62	0.63	0.64	0.65	0.65	0.62	0.67
Sweden	0.45	0.47	0.47	0.49	0.50	0.51	0.50	0.50	0.51
Austria	0.55	0.55	0.57	0.57	0.57	0.55	0.55	0.57	0.61
Czech Republic	0.62	0.64	0.63	0.62	0.61	0.60	0.61	0.62	0.65
Poland	0.62	0.61	0.63	0.60	0.60	0.57	0.62	0.61	0.60
Slovenia	0.51	0.52	0.51	0.50	0.50	0.47	0.51	0.50	0.51
Finland	0.44	0.45	0.47	0.49	0.51	0.53	0.55	0.57	0.60
Slovakia	0.31	0.32	0.33	0.34	0.35	0.35	0.35	0.37	0.37
Lithuania	0.50	0.50	0.47	0.47	0.52	0.45	0.47	0.51	0.54

TABLE 2 | Average energy efficiency.

Counties	Avg. EE
Denmark	0.90
Spain	0.94
Netherlands	0.49
Italy	0.43
Belgium	0.93
Bulgaria	0.68
France	0.46
Romania	0.48
Ireland	0.64
Luxembourg	0.46
Hungary	0.56
United Kingdom	0.50
Portugal	0.55
Greece	0.61
Germany	0.50
Estonia	0.63
Sweden	0.49
Austria	0.56
Czech Republic	0.62
Poland	0.60
Slovenia	0.50
Finland	0.51
Slovakia	0.35
Lithuania	0.49

argument consents that there is no critical variation of mean EE amongst the new and the old European Union nation states.

The findings in table three show that Denmark plus Spain obtained the maximum effect marks (Denmark 0.83 to 1 and Spain 0.81–94) whereas Slovakia obtained the lowest EE mark between 0.30–0.36. Ultimately, the findings give the mean efficiencies marks in three varied methods. Within the initial column, the mean efficiency score for the period is between 2010–2018, **Table.3**. Similarly, the subsequent columns give the mean efficiency marks for two varied phases: the initial one alongside a comprehensive, integrated subsidy and the next after the completion of the disintegrated subsidy program. Owing to lack of data, the number of years concerning the two-time is equivalent.

Energy Efficiency by Russell Measure Model

The findings in table four, give the change of EE in the main sectors of member countries, in addition to its fundamental parts, for the time between 2010–2008. It has to be said that even though there are already existing ecological prevailing circumstances in addition to the primary sector falls, particularly after the year 2012, during which the original disintegrated grant program was utilized. On the other hand, EE after 2016, the direct changes of EE in 2010–2018 look to overshadow the fall of ecological efficiency, hence leading to direct variations in EE.

It is observable that the nations depicted as green have the biggest mean statistics evaluated within the timeframe., i.e., Spain at 90.8%, the United Kingdom at 90.71%, and Hungary (87.24%). Inversely, the Czech Republic with 36.68% depicts the lowest mark throughout the evaluated timeframe of **Table 4**. In order to additionally examine the marks derived using the dynamic envelope analysis approach, the findings show the change concerning the dynamic envelope analysis mark per nation within the time evaluated. It is crucial to emphasize nearly all

TABLE 3 | Energy Efficiency through Slack-based DEA model.

Counties	2010	2011	2012	2013	2014	2015	2016	2017	2018
Denmark	1.00	0.96	0.94	0.83	0.83	0.81	0.83	0.83	0.83
Spain	0.96	1.00	0.94	0.94	0.94	0.83	0.81	0.83	0.94
Netherlands	0.45	0.49	0.43	0.45	0.48	0.50	0.50	0.48	0.45
Italy	0.36	0.40	0.40	0.41	0.42	0.43	0.43	0.42	0.45
Belgium	0.94	0.94	0.96	0.83	0.83	0.81	0.83	1.00	0.96
Bulgaria	0.62	0.58	0.61	0.64	0.76	0.76	0.64	0.64	0.59
France	0.43	0.42	0.45	0.41	0.42	0.43	0.45	0.45	0.48
Romania	0.43	0.45	0.45	0.47	0.48	0.45	0.48	0.45	0.52
Ireland	0.64	0.62	0.59	0.64	0.61	0.57	0.64	0.61	0.64
Luxembourg	0.40	0.41	0.42	0.43	0.43	0.45	0.45	0.48	0.48
Hungary	0.57	0.59	0.57	0.57	0.55	0.53	0.49	0.51	0.49
United Kingdom	0.49	0.50	0.48	0.48	0.53	0.47	0.43	0.45	0.45
Portugal	0.50	0.51	0.52	0.53	0.53	0.55	0.55	0.55	0.57
Greece	0.57	0.59	0.61	0.62	0.61	0.59	0.57	0.55	0.58
Germany	0.48	0.51	0.45	0.45	0.45	0.47	0.48	0.53	0.50
Estonia	0.57	0.58	0.59	0.60	0.61	0.62	0.62	0.59	0.64
Sweden	0.43	0.45	0.45	0.47	0.48	0.49	0.48	0.48	0.49
Austria	0.53	0.53	0.55	0.55	0.55	0.53	0.53	0.55	0.58
Czech Republic	0.59	0.61	0.60	0.59	0.58	0.57	0.58	0.59	0.62
Poland	0.59	0.58	0.60	0.57	0.57	0.55	0.59	0.58	0.57
Slovenia	0.49	0.50	0.49	0.48	0.48	0.45	0.49	0.48	0.49
Finland	0.42	0.43	0.45	0.47	0.49	0.51	0.53	0.55	0.57
Slovakia	0.30	0.31	0.32	0.33	0.34	0.34	0.34	0.36	0.36
Lithuania	0.48	0.48	0.45	0.45	0.50	0.43	0.45	0.49	0.52

nations depict an increasing trend for their marks. Principally, the nations that attain the maximum marks demonstrate a direct change in their efficiency scores.

Sensitivity Analysis

The findings of the robustness results are displayed in **Table 5**. The results show that electricity supplies originating from RE types are direct and meaningful at a one percent stage and advance the efficiency of the European Union nations concerning electric vehicle embracement. Nonetheless, when the initial units of the two-pronged equation are ascertained it is observable that RE electricity production is not meaningful, statistically elucidating the likelihood of each nation being at the efficiency frontline. The order aspect, say when the efficient nations are without the approximation, depicts that RE generation expands the dynamic envelope analysis mark. Inversely, the presence of peak electricity use phases reduces the efficiency of the nations in terms of electric vehicle embracing within the individual part equation and thus attains an equalizing impact on the dual initial and the next part of the two-pronged equation.

Furthermore, the coefficient of government charging points and population attaining tertiary or further education are direct and meaningful at a one percent level. This conforms with what was theoretically anticipated regarding the dual, one aspect equation and the second number on a two-pronged equation. Besides, grants for B electric vehicles acquiring are meaningful within the approximations showing their focal importance to increase B electric vehicles market proportion, even though alongside reduced points of meaningfulness within the initial part of the two-pronged equations. Additionally, the percentage amongst imports as well as trade from abroad (RMX) contributes to growing the dynamic envelope analysis-static returns to scale mark, within the first equation, and equally to send the inefficient nations closer to the efficiency frontline at one percent meaningful. (Using the second part of the two-pronged equation). The following inline variable used to evaluate the population's propensity to possess a charging point at home attains a significant coefficient in the dynamic envelope analysis-static returns to scale mark within the estimation.

Ranking of Efficiency

Table six gives EE marks across different means. The initial column gives the EE for the timeframe of 2010–2018. The subsequent dual columns present the EE marks for the two varied timeframes: the initial one alongside a complete integrated grant, and the next for the execution of an integrated grant program. Owing to the lack of data, the number of years concerning the dual sub-phases is not equivalent. There are meaningful suggestions for a significant segment of the nations that the novel grant program did not provoke further advancement of the dual-energy and ecological efficiency, irrespective of the strong commitment about this as an important goal from the European Union members. **Table 6** shows the ranking of energy efficiency score.

Other than the already energy efficiency advanced nations, the ones that have advanced their EE are only those that have advanced their efficiency marks, such as the UK, Portugal, Germany, Austria, Poland, Lithuania, and Latvia. It is clear from those above that many factors underpin the non-conformity of EE amongst nations putting into action a similar agricultural program for an extended timeframe. However, this research could not give a precise basis for this unconventionality due to data paucity. Nonetheless, clues exist

TABLE 4 | Energy efficiency through russel measure model.

Counties	2010	2011	2012	2013	2014	2015	2016	2017	2018
Denmark	1.00	1.00	0.98	0.86	0.86	0.84	0.86	0.86	0.86
Spain	1.00	1.00	0.98	0.98	0.98	0.86	0.84	0.86	0.98
Netherlands	0.47	0.51	0.45	0.47	0.50	0.52	0.52	0.50	0.47
Italy	0.37	0.41	0.42	0.43	0.44	0.45	0.45	0.44	0.47
Belgium	0.98	0.98	1.00	0.86	0.86	0.84	0.86	1.04	1.00
Bulgaria	0.65	0.61	0.64	0.67	0.79	0.79	0.67	0.67	0.62
France	0.45	0.44	0.47	0.43	0.44	0.45	0.47	0.47	0.50
Romania	0.45	0.47	0.47	0.49	0.50	0.47	0.50	0.47	0.54
Ireland	0.67	0.65	0.62	0.67	0.64	0.60	0.67	0.64	0.67
Luxembourg	0.42	0.43	0.44	0.45	0.45	0.47	0.47	0.50	0.50
Hungary	0.60	0.62	0.60	0.60	0.57	0.55	0.51	0.53	0.51
United Kingdom	0.51	0.52	0.50	0.50	0.55	0.49	0.45	0.47	0.47
Portugal	0.52	0.53	0.54	0.55	0.55	0.57	0.57	0.57	0.60
Greece	0.60	0.62	0.64	0.65	0.64	0.62	0.60	0.57	0.61
Germany	0.50	0.53	0.47	0.47	0.47	0.49	0.50	0.55	0.52
Estonia	0.60	0.61	0.62	0.63	0.64	0.65	0.65	0.62	0.67
Sweden	0.45	0.47	0.47	0.49	0.50	0.51	0.50	0.50	0.51
Austria	0.55	0.55	0.57	0.57	0.57	0.55	0.55	0.57	0.61
Czech Republic	0.62	0.64	0.63	0.62	0.61	0.60	0.61	0.62	0.65
Poland	0.62	0.61	0.63	0.60	0.60	0.57	0.62	0.61	0.60
Slovenia	0.51	0.52	0.51	0.50	0.50	0.47	0.51	0.50	0.51
Finland	0.44	0.45	0.47	0.49	0.51	0.53	0.55	0.57	0.60
Slovakia	0.31	0.32	0.33	0.34	0.35	0.35	0.35	0.37	0.37
Lithuania	0.50	0.50	0.47	0.47	0.52	0.45	0.47	0.51	0.54

TABLE 5 | Sensitivity analysis.

Counties	2010	2011	2012	2013	2014	2015	2016	2017	2018
Denmark	1.00	1.00	0.99	0.87	0.87	0.85	0.87	0.87	0.87
Spain	1.00	1.00	0.99	0.99	0.99	0.87	0.85	0.87	0.99
Netherlands	0.47	0.51	0.45	0.47	0.50	0.52	0.52	0.50	0.47
Italy	0.38	0.42	0.42	0.43	0.44	0.45	0.45	0.44	0.47
Belgium	0.99	0.99	1.00	0.87	0.87	0.85	0.87	1.00	1.00
Bulgaria	0.65	0.61	0.64	0.67	0.80	0.80	0.67	0.67	0.62
France	0.45	0.44	0.47	0.43	0.44	0.45	0.47	0.47	0.50
Romania	0.45	0.47	0.47	0.49	0.50	0.47	0.50	0.47	0.54
Ireland	0.67	0.65	0.62	0.67	0.64	0.60	0.67	0.64	0.67
Luxembourg	0.42	0.43	0.44	0.45	0.45	0.47	0.47	0.50	0.50
Hungary	0.60	0.62	0.60	0.60	0.57	0.55	0.51	0.53	0.52
United Kingdom	0.51	0.52	0.50	0.50	0.55	0.49	0.45	0.47	0.47
Portugal	0.52	0.53	0.54	0.55	0.55	0.57	0.57	0.57	0.60
Greece	0.60	0.62	0.64	0.65	0.64	0.62	0.60	0.57	0.61
Germany	0.50	0.53	0.47	0.47	0.47	0.49	0.50	0.55	0.52
Estonia	0.60	0.61	0.62	0.63	0.64	0.65	0.65	0.62	0.67
Sweden	0.45	0.47	0.47	0.49	0.50	0.51	0.50	0.50	0.51
Austria	0.55	0.55	0.57	0.57	0.57	0.55	0.55	0.57	0.61
Czech Republic	0.62	0.64	0.63	0.62	0.61	0.60	0.61	0.62	0.65
Poland	0.62	0.61	0.63	0.60	0.60	0.57	0.62	0.61	0.60
Slovenia	0.51	0.52	0.51	0.50	0.50	0.47	0.51	0.50	0.51
Finland	0.44	0.45	0.47	0.49	0.51	0.53	0.55	0.57	0.60
Slovakia	0.32	0.33	0.34	0.35	0.36	0.36	0.36	0.38	0.38
Lithuania	0.50	0.50	0.47	0.47	0.52	0.45	0.47	0.51	0.54

concerning joining inefficiency alongside the composition of the primary areas of every single European Union member. The rationale that the European nations are centered on arable crops, as well as concentrated animal husbandry activity, lend credence to the progression of their ecological efficiency after the disintegration of the payments, corroborating the importance of these variations, and ensuring compliance from the primary areas entirely to the European Union's ecological plan of actions. Now, all these analyses need to be corroborated after finishing the timeframe between 2010–2018, during which the vital data is made accessible. Nonetheless, it is crystal clear that between the European Union nations, irrespective of the reality that there is a

TABLE 6 | Ranking of energy efficiency.

Countries	2010–2013	2013–2016	2013–2018
Denmark	1	1	1
Spain	0.9	0.9	0.9
Netherlands	1	0.9	0.9
Italy	0.9	1	0.9
Belgium	0.9	0.9	1
Bulgaria	0.9	1	0.9
France	0.8388	0.8532	0.7956
Romania	0.8118	1	0.5481
Ireland	0.8073	0.8532	0.6678
Luxembourg	0.7605	0.7857	0.684
Hungary	0.747	0.7713	0.6732
United Kingdom	0.7056	0.6966	0.7335
Portugal	0.702	0.6957	0.7209
Greece	0.6948	0.7614	0.495
Germany	0.6561	0.6282	0.738
Estonia	0.6102	0.6129	0.6012
Sweden	0.5859	0.6336	0.441
Austria	0.5616	0.5553	0.5832
Czech Republic	0.549	0.639	0.2781
Poland	0.5391	0.4869	0.6957
Slovenia	0.4437	0.4797	0.333
Finland	0.4293	0.4536	0.3573
Slovakia	0.3996	0.4068	0.3771
Lithuania	0.3951	0.3708	0.4689
Latvia	0.3771	0.2826	0.6597
Average	0.6804	0.6903	0.6498

unified agricultural policy being executed after the establishment the European Union, there are significant changes concerning significant challenges for the European Union, such as the energy and ecological efficiencies policies.

CONCLUSION AND POLICY IMPLICATIONS

In this paper, the energy and environmental efficiency of the European nations are evaluated—the timeframes chosen entail two-pronged phases of the execution of the varied subsidy programs. The dynamic envelope analysis, which was selected for the analysis, showed significant changes in efficiency marks amongst nations for the dual-energy and ecological efficiency. The significant findings, mainly regarding the more established member countries, likely mean that even though for several years now a similar energy policy has been instituted by every European nation, the differences in efficiency marks are profound, implying that different parameters form the requirements for energy as well as the combination of vital key-ins for agricultural production. The change outlines a relatively economics-focused environment because inefficient nations need to promote agricultural products in a harmonized marketplace without trade restrictions. Cleaner production will shape the course of industrial activity within the years ahead due to its economic nature, and hence needs to be encouraged and met with strong commitment from member countries. The suggested approach could be applied as a consistent policy assessment instrument for such evaluations.

Regarding the initial stage, the key findings imply that the European Union, on average, is off track from reaching its efficiency frontline. This implies that key-ins have been inefficiently applied. In reality, nations can expand their B electric vehicles adoption points and execute electric mobility policies to utilize similar key-ins. Furthermore, from the next stage of the analysis, the top results illustrate a direct and statistically meaningful impact of RE electricity production within the dynamic envelope analysis. i.e., static returns to scale marks in the two one aspect evaluation plus the second aspect of the two-pronged assessment equations. This connotes those nations, alongside high intensities of RE electricity production, could be efficient in scaling up B electric vehicles since they can create charge points together with power produced from RETs. Concurrently, peak power consumption reduces the dynamic envelope analysis constant returns to scale.

Equally, Germany is efficient within all the scenarios given regarding the dynamic envelope analysis models. It is one of the nations of the European Union with high-quality incineration, recycling of material, and composting of waste and sends a minute amount of waste to landfill. However, France, Italy, the Netherlands, Spain, and Sweden generally apply all waste argument strategies, and Sweden too sends almost no waste to landfill. Simultaneously, Sweden is efficient in the entire dynamic envelope analysis as well. Also, the out-of-the-blue result pertains g to the United Kingdom that is efficient within the models nonetheless yet depended on the landfill in the year 2008. Nevertheless, this reduces as time goes by. Generally, it is observed that nations that apply all the four management strategies together with additional sustainable ones and reduce the utilization of landfills are efficient based on the dynamic envelope analysis and the circular economy method.

Of course, the article also has insufficient research. We believe that follow-up research can further break through the restrictions and consider the energy efficiency interaction between EU member states based on existing research prospects. Our perspective should be based on the group nature of their organization, using methods such as spatial correlation models and spatial metrology to analyze the results of energy efficiency under the influence of economic channels.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

HL: Conceptualization, Data curation, Methodology, Writing—original draft. PY: Data curation, Visualization.

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The Fiscal Hedging and Green Financing: Sustainability Challenges for Developing World

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The global community has set intensive targets in Sustainable Development Goals (SDGs) to better people's lives after closing the Millennium Development Goals (MDGs). It corresponds to the 2030 aspirations of the United Nations to enhance and promote the sustainable development of human society. The current paper explores the impact of fiscal hedging and R&D in energy Using a green-energy system in SDGs. To do this, we used TOPSIS and QARDL methodologies on a 21-year dataset of South and Southeast Asian economies from 2000 to 2020. The study results show that fiscal hedging contributes favourably to the environmental degradation of the underlying economy. Research and development (R&D) in renewables has contributed negatively to ecological degradation and SDGs in the economies of South & Southeast Asia. This study suggests policy guidelines for advanced and developing economies based on fiscal stability and technical innovation through R&D to meet SDG.

Keywords: green finance, fiscal hedging, QARDL model, TOPSIS, sustainability

INTRODUCTION

The changing climate is escalating and impacting people through the activation of unpleasant situations such as storms, forest fires and floods. It involves preparing to cope with the effects of climate change. According to the Paris agreement, it will emerge that we can halt global warming by two degrees Celsius. The global population is predicted to expand up to 85 thousand million by the end of 2030 (Desa, 2015). It is expected that 90% of humans are inhaling poisonous oxygen. If we do not minimize carbon emissions to lessen the rate of respiratory diseases, 7 million more humans will lose their lives per year. Contaminated water causes 5 million fatalities every year and adds to significant threats to health (World Health Organization, 2018). Extinction-threatened species have lost approximately 8 percent of their habitat during the last 2–3 decades (Schaffer-Smith et al., 2016). In addition, another 22 percent of the species are in danger of rapid depletion of breeding, endangered species introduction, and global warming.

The emerging world is faced with a dynamic economic development process, with environmental conservation to achieve sustainability. Fiscal imbalances became an immediate issue in almost every developing country in the economy's growth as the emergence of fiscal deficits adapted the imbalance in the short term. Simultaneously, an environmental effect is also unsatisfactory. The rising budget deficit calls for fiscal stabilization. The intertemporal nexus between fiscal imbalance and ecological conditions has become an extensive debate and research subject.

Fiscal imbalances and have financial and social costs. According to the UN Development Program (UNDP), infant mortality rates, illness, analphabetic, and malnutrition are significantly higher in the heavily indebted and fiscal imbalance developing countries than other developing countries (Hager, 2016). It has been estimated that eighty-six percent (six out of seven) of African countries spend more resources on debt servicing (i.e., interest and principal repayments) than on projects like literacy, child mortality, malnutrition, and primary health care services. It is expected that spending such money (debt service) can help five million children survive for their fifth birthday, and millions of malnutrition cases would be stopped (Pettifor, 2002).

Emerging economies have already undergone instability cycles under the current wave of debt accumulation, while the COVID-19 pandemic struck extreme financial stress on these economies. Other vulnerabilities such as increasing fiscal and current account deficits and adopting riskier debt further complicate these economies' capacity to sustain financial stress. In percentage, the government debt (in percentage) owned by non-resident investors increased to 43%, and corporate debt denominated in foreign currencies grew 26% of GDP in 2018. A decade of recurring growth disappointment has followed a rising stock of fiscal deficit and a riskier debt composition in these economies. The technological innovation promises to address modern nations' environmental concerns by advancing towards a cleaner, lower carbon atmosphere. Thus, technologies without environmental damage are essential to preserving and improving living standards. Scientists would be convinced that environmental breakthroughs in technology are the only way to save our globe. Emerging innovations have traditionally been established in response to demographical concerns and requirements.

According to the United Nations, more than 60% of Carbon footprints are generated by oil. In comparison, 13% of the world's people have no light, while over three billion people are dependent on coal and oil for their heating and cooking (Bennion et al., 2015). This circumstance requires energy transfer to a cleaner type that supports a more affluent, sustainable, and environmentally friendly, inclusive society, considering environmental issues. Experts have demonstrated to use of so-called renewable energies to prevent climate change. Researchers are attempting to produce improvements to mitigate global climate change. Experts claim that so-called green solutions be used to protect the environment. Scientists strive to develop ideas to mitigate greenhouse gases and environmental issues globally. There are numerous ways in the future to deal with energy shortages. The first of two ideas on ecological sustainability above political and cultural concerns distinguish green technology from environmental sustainability. Sustainable development supporters suggest that green energy is non-existent but can only be established and explored. With the support of sustainable technology, sustainable development will occur. Sustainability depends on technological advancement, which further minimizes carbon dioxide emissions.

The remaining components of the investigation are as follows. The next part is a brief description of the literature. Section 2 illustrates the analytical process. The results are detailed in section 3 and section 4 examines the conclusions and discusses the policy implications.

Literature Review

In recent years, environmental and energy economists have drawn attention to the relationship between fiscal Instruments and ecological efficiency. However, the experiments in the current literature are quite limited (Yuelan et al., 2019) noted that instruments of fiscal imbalance have substantially increased long-term environmental degradation in China. The United States' government investments hurt the climate (Yoshino et al., 2021). There are temporary carbon dioxide emissions, public revenue, and government spending patterns. The (Ullah et al., 2020) study indicated that fiscal-instrument shock would worsen environmental quality in selected economies in Asia, except Japan, which tends to boost environmental quality with broad fiscal imbalances.

The environmental impacts of fiscal instruments can vary depending on their emission source, i.e., whether pollution is caused by production or consumption (Lederer et al., 2018; Taghizadeh-Hesary and Yoshino, 2020) identified the different means through which public spending can influence the environment's quality for pollutants emitted by production. Because of pollution produced by consumption, fiscal expenditures in fields such as education and health enhance consumers' present and future revenues and decrease environmental quality. On the other hand, the higher levels of government expenditure help create environmental legislation, compliance, and productivity, which can help build institutions that improve environmental quality (Rasoulinezhad et al., 2020; Ike et al., 2020; Shan et al., 2020). Proposed four channels by which fiscal expenditure could affect atmospheric pollution concentrations, namely "size, structure, method, and income effects." Additionally, (Sun Y. et al., 2020) distinguish between public expenditure's direct and indirect environmental impacts. Government expenditure is being used both explicitly and implicitly to mitigate environmental impact, although the impact of government expenditure on carbon emissions is not definitive.

The fiscal imbalance negatively affects environmental quality, spreading beyond a country's borders. Therefore, rectifying a single country's fiscal imbalance issue cannot address the region's ecological concern. According to (Li et al., 2020), regions with a substantial improvement in fiscal imbalance have sufficient funds for environmental governance, manage environmental laws effectively, and reduce regional ecological contamination. Thus, the externalities of environmental contamination and the positive spillover effect of environmental governance usually give rise to a "free-riding" phenomenon between regions. This growth leads to competing rather than collaboration with the inter-regional environmental governance model (Chang, 2019). Contrarily, increasing fiscal imbalance in the regional governance arrangement would lessen environmental status, draw international investments' attention, and improve revenue collection through tax. This phenomenon leads to a "race to the bottom" ecological governance and the source of environmental deterioration (Wang et al., 2019).

Moreover, (Abbas et al., 2020b) suggested that the fiscal imbalance has a notable impression on selecting regional administration spending behaviour at the institutional level. Thus, the biased structure becomes increasingly severe as the fiscal imbalance (Li, 2018). As a result, it is also expected that the higher the level of expansion of fiscal imbalance, the higher the misallocation of resources, and the result will be the loss of efficiency (Sun H. et al., 2020; Iqbal N. et al., 2020). Individual countries progressively impose huge taxes and financing on infrastructure and building programs because of fiscal income and spending imbalances. It raises taxes, threatens mass livelihood security, and enhances environmental consequences, not boosting environmental governance and productivity. (Zhou et al., 2019; Abbas et al., 2020a). Besides, the regional government assumes the environmental policymaker's responsibility and undertakes the implementation (Anser et al., 2020a).

Across history, creativity has been an integral part of economic development. New technology, creative mechanisms to minimize the divide between developing and developed countries should be built (Pigliautile et al., 2020). In each case, some technologies–including those with substantial economic consequences–can involve unavoidable trade-offs which need to be identified, evaluated, and addressed (Jorge, 2018). The advancement of energy technologies will achieve sustainability (Iqbal W. et al., 2020; Iram et al., 2020). It is only feasible if worldwide fossil fuel consumption is reduced. Technical measures should enhance energy supply, efficiency, and a more environmentally sustainable transition to oil and coal technology. Renewable energy technologies go out quicker than ever and are readily accessible to the general public (Viteri et al., 2019). Environmental technologies are designed to promote energy efficiency in the economic sectors (Anser et al., 2020b). Businesses must use green technology to ensure environmentally-friendly (Marseglia et al., 2020). We need to build indigenous technological expertise that contains skilled professionals, academics (Hanif et al., 2019).

The recent research attempted to explore this relationship with different methods. For example, (Katircioğlu et al., 2018) have checked Turkey's value of environmental quality fiscal instruments utilizing linear ARDL (Ullah et al., 2021). Consult with the asymmetrical or non-linear autoregressive distributed lag (NARDL) method for these two parameters' asymmetric effect in Pakistan. (Hanif et al., 2019) applied ECM to investigate fiscal instruments' short and long-term role with renewable energy at CO2 emission levels. Similarly, (Akhmat et al., 2014) implemented the FMOLS technique and validated it for SAARC nations (Jebli et al., 2016) has used panel FMOLS and DOLS frameworks to OECD countries and endorsed the correlation between fiscal instruments and environmental degradation.

Studies have recognized the correlation between environmental degradation and financial indicators, but fiscal factors in the outgoing literature remain lacking. The fiscal position of ecological quality can both enhance and mitigate Carbon emission. Fiscal policy tools are described as income impact, structure effect, and technical effect. Income impact: Higher income, typically linked to increased public spending, boosts demand for better environmental quality. Structure effect: Substantial fiscal expenditure encourages less disruptive environmental practices than practices that exacerbate physical wealth. Technical effect: This mechanism also aims to reduce environmental pollution, increasing labour productivity correlated with improved government health and educational expenditure costs. Therefore, this analysis contains and outlines the effect of fiscal policy instruments and government spending on environmental degradation. Over the period 2000–2020, the current study examines the complex relationships between fiscal policy tools and Carbon emission for Southeast Asian countries. This research's scope is broader because the research concentrates on fiscal policy and the relatively limited economy. The existing studies concentrated on the fiscal policy's public spending component; thus, few studies focus on government spending and income instruments. The issue of environmental degradation due to GHG emissions can only be addressed with the necessary fiscal retort. There is no need for positive and adverse shocks to have a linear impact on fiscal policy instruments' environmental efficiency. It is, therefore, necessary to assess the asymmetric effect on ecological efficiency of the modifications to fiscal policy tools. Our research diverges from the empirical literature by suggesting that fiscal policy tools' impacts on environmental efficiency may be asymmetrical. That is, why in this study, we used the QARDL methodology. This study also applied the TOPSIS method to view the underlined economies' overall efficiency to understand better their economic, energy, fiscal, and environmental conditions.

DATA AND METHODOLOGY

This study analyzed the 21 years (2000–2020) of six developing economies (three from South and Southeast Asia each). The dataset was collected from the International Energy Agency's (IEA 2020), IMF, and World Development Indicators (WDI) comprises 11 separate parameters of South & Southeast Asian nations (see **Appendix 1**). These parameters have been divided into four distinct categories. As an ecological index (ENV), the air and greenhouse gas emissions (Tonne cap) and air pollution (10 million HAB) were developed, with the energy index including renewable energy (KTOE) and renewable energy (GDP percent) (ENG). The General Government Deficit (percent GDP) and Real Interest Rate percent were developed in a fiscal index (FIL). Subsequently, a Financial Index (ECO) was built utilizing the USD, exports (GDP percentage), consumer price indices (CPI percentage), and GDP (current USD).

TOPSIS is a good choice for making multi-attribute decisions because of its simplicity and quickness. However, TOPSIS has two key limitations: rank reversal and invalidation of Euclidean distance. To overcome the shortcomings to evaluation, this study incorporates absolute optimized solutions (Che et al., 2021) and virtual negative ideal solutions.

(1) Creating a judgment matrix with a starting point. As a result, the performance of the measure j for nation i is denoted by $i, i \in [1, m]$, $j \in [1, 11]$ the abbreviation $A = [a_{ij}]$.
(2) In order to derive the usual decision matrix $C = [c_{ij}]_{m \times 11}$ right mtimes11, the non-dimensional parameter A is analyzed.
(3) Designing weighted decision tables. The weights generated by a rough set and a large-scale survey are used since the value of variables to evaluation differs.

Let $D = [d]_{ij}$ be the weighted decision matrix with $d_{ij} = \sum_{i=1}^{m} c_{ij} \times \omega_j, \omega_j > 0$ and $\sum \omega_j = 1$.

(4) Choosing the best possible options. Rankings are reversed because of selecting optimal solutions at random. Absolute positive and negative ideal solutions determine indicators during our period studied. The number of subjects (countries) in this study will remain the same because of a lack of data. The maximum and the minimum will not grow or contract. To put it another way, the absolute optimistic ideal solutions are defined as $D^{+} = \{d^{+}_{1worst}, d^{+}_{2worst}, \cdots, d^{+}_{11worst}\}$, where d^{+}_{jworst}, and so on. To determine an absolute negative suitable solution, we can use the following formula: $D- = \{d^{-}_{1best}, d^{-}_{2best}, \cdots, d^{-}_{11best}\}$, where d^{-}_{jbest}, where d^{-}_{jbest} best is the highest of the given index j.
(5) Improve TOPSIS by incorporating a virtual negative optimal situation. Virtual negative ideal solutions $D^{*} = \{d^{*}_{1}, d^{*}_{2}, \cdots, d^{*}_{11}\}$ $(where\, d^{*}_{j} = 2d^{-}_{jworst} - d^{+}_{jbes})$ take over from the absolute negative ideal solutions D^{-} to avoid Euclidean distance invalidation. The Euclidean distances are calculated with $S^{+}_{i} = \sqrt{\sum_{j}^{11} (d_{ij} - D^{+}_{jbes})^2}$ and $S^{*}_{i} = \sqrt{\sum_{j}^{11} (d_{ij} - D^{*}_{j})^2}$, respectively.
(6) The relative closeness is defined as $E^{*}_{i} = \frac{S^{+}_{i}}{S^{+}_{i} + S^{*}_{i}}$ where $0 \le E^{*}_{i} \le 0.5$. The countries with E^{*}_{i}, in order of least to greatest increase, are ranked.

Rough set, a large-scale survey and enhanced TOPSIS are used to create an integrated strategy that involves three steps: data preprocessing, weighted decision matrix and modified TOPSIS evaluation.

At the outset, we create a decision matrix $A = [a_{ij}]_{m \times 11}$ and $b_{ij} = -a_{ij}$ to turn negative indicators into positive ones It is followed by a second step in which the non-dimensional quantity A is evaluated to obtain the standard decision matrix $C = [c_{ij}]_{m \times 11}$ which is a fixed-base difference approach.

Because it uses a single reference point, the fixed-base difference approach can capture spatial and temporal differences among indicators. We perform the following calculation: It's the ratio of $c_{ij} = (b^{t}_{ij} - b^{t_0}_{j.min}) / (b^{t_0}_{j.max} - b^{t_0}_{j.min})$, $b^{t_0}_{j.max}$ and $b^{t_0}_{j.min}$ that is, the maximum and minimum of the jth indicator in year t_0 *and* $c_{ij} < 0$ are two ways to look at this: one is to look at how well the country has progressed since the beginning of time (t 0), and another way is to look at how well the country has gone since t 1.

Finally, the weights are computed by multiplying the subjective and objective values.

$$W_j = \left(\prod_{k=1}^{m} W^{k}_{j}\right)^{1/k} \Big/ \sum_{j=1}^{n} \left(\prod_{k=1}^{m} W^{k}_{j}\right)^{1/k}$$

There is a total of m different weighing methods in the formula W^{k}_{j}, with k, j being the indicator number and m being the weight by method number.

Quantile Regression for Panel Data

Consider the following model

$$Y_{it} = X^{'}_{it}\, \theta(U_{it}) + \alpha_i, \quad t = 1, \dots, T, \quad i = 1, \dots, n \tag{1}$$

Where $(Y_{it}, X_{it}) \in \mathbb{R} \times \mathbb{R}^{k}$ are a definite factor and $(U_{it}, \alpha_i) \in \mathbb{R} \times \mathbb{R}$ are unobservable? The vector X_{it} is supposed to involve a constant term, i.e., $X^{'}_{it} = (1, X^{s}_{it})$ with $X^{s}_{it} \in \mathbb{R}^{k-1}$. The function $\tau \to X'\theta(\tau)$ is supposed to be rigorously expanding in $\tau \in (0, 1)$ and the factor of attention is supposed to be $\theta(\tau)$. If αi were detectable, it would adhere to that

$$P\left[Y_{it} \le X^{'}_{it}\, \theta(\tau) + \alpha_i | X_i, \alpha_i\right] = \tau \tag{2}$$

Based on the premise that $U_{it} \sim U[0, 1]$ conditional on the value of a given $X_i = (X^{'}_{i1}, \dots, X^{'}_{iT})'$ in the range of 0–1, and the value of a given α_i. There has been a lot of use of this representational style in the literature (Chernozhukov and Hansen, 2008). According to (Koenker, 2004), there is a discrepancy between the model in **Eq. 2** and the typical quantile regression model established by (Koenker, 2004). This random variable could be arbitrarily related to the rest of the random variables in **Eq. 2** [i.e., $(i.e.\alpha_i = \alpha_i(U_{it}, X_i, \eta_i))$ for some i.i.d. sequence η_i] rendering condition (2.2) as not especially beneficial in order to detect the presence. This raises the question of whether or not the factor $\theta(\tau)$ can be reliably recognized and calculated from the data under any further requirements on (U_{it}, α_i) (Rosen, 2012) recently demonstrated that quantile limitation alone does not identify theta if variables are taken into account $\theta(\tau)$. So, if $QZ(\tau|A)$ stands for $\tau - quantile$ conditional on A, let $e_{it}(\tau) \equiv X^{'}_{it}[\theta(U_{it}) - \theta(\tau)]$, is equivalent to Z and the model depicted by **Eq. 3**.

$$Y_{it} = X^{'}_{i}\theta(\tau) + \alpha_i + e_{it}(\tau), Qe_{it}(\tau)(\tau|X_i) = 0 \tag{3}$$

In such case, the considerations limitation $Qe_{it}(\tau)(\tau|X_i) = 0$ does not have enough identification power. 1 Assumption such as support requirements and some type of conditional independence of $e_{it}(\tau)$ throughout time, which (point and partially) identify $\theta(\tau)$, are then provided by (Rosen, 2012). (Chamberlain, 1982) correlated random-effects model is used by (Abrevaya and Dahl, 2008) to obtain an estimate of $\theta(\tau)$. Modeling the unobservable in terms of linear projections onto the scene ones, as well as a perturbation, is the goal of this model

$$\alpha_i(\tau, X_i, \eta_i) = X^{'}_{i}\wedge_T(\tau) + \eta_i.$$

Whenever η_i is not disturbed, a regression analysis like this one can be used to determine the value of $\theta(\tau)$. Even yet, a quantile limitation alone cannot identify $\theta(\tau)$ when a non-trivially

TABLE 1 | Score of positive indicators in South-East Asia.

	GDP (CAP$)	Renewable	
		(KTOE)	R&D (% of GDP)
India	2005.86	217899	0.65
Pakistan	1482.31	42658	0.27
Bangladesh	1698.35	9747	3.13
Indonesia	3893.85	144726	0.23
Vietnam	2566.60	16189	0.55
Philippine	3225.09	25759	0.19

occurring η_i is present. It is obvious since $X_{it}^{'}\theta(U_{it}) + X_i^{'}T(\tau) + \eta_i$ conditional behaviour is dependent on both the distribution of the unobservables U_{it} and η_i. The correlated random-effects model may not work well in many circumstances since even a fully described function for $\alpha_i(\tau, X_i, \eta)_i$ does not help in determining $\theta(\tau)$. There are other ways to address this problem; however (Koenker, 2004) adopts a new approach and regards the $\{\alpha_i\}_{i=1}^{n}$ as parameters that must be jointly estimated for each $\theta(\tau)$ of q various quantiles. He suggests using an estimator that is, reprimanded.

$$\tilde{\theta}\{\tilde{\alpha}_i\}_i^n = 1 \equiv \underset{\left(\theta, \{\alpha_i\}_{i=1}^n\right)}{\operatorname{argmin}} \sum_{k=1}^{q}\sum_{i=1}^{n}\sum_{t=1}^{T}\rho_{\tau_k}\left[Y_{it} - X_{it}^{'}\theta(\tau_k) - \alpha_i + \lambda\sum_{i=1}^{n}|\alpha_i|\right. \tag{4}$$

A penalization parameter, λ is used to reduce the $\tilde{\alpha}s$ to the same value, $\rho_\tau(u) = u[\tau - I(u<0)]$, $I(\cdot)$ is the indicator function. For example, solving **Eq. 4** can be computationally intensive when the number of variables is significant. It is especially true if n is more excellent than $\lambda \geq 0$. Non-separable panel data models, on the other hand, have their literature. These models can provide quantile treatment effects since they are flexible enough (Chernozhukov and Hansen, 2008; Graham and Powell, 2008). There is some evidence that the quantile treatment impact of interest can be partially detected (for fixed T) in the model, as (Chernozhukov and Hansen, 2008) demonstrate.

$$Y_{it} = g0(X_{it}, \alpha_i, U_{it}), \quad \mathrm{U_{it}}\big|\mathrm{X_i}, \alpha_\mathrm{i} =^{\mathrm{d}} \mathrm{U_{it'}}\big|\mathrm{X_i}, \alpha_\mathrm{i} \tag{5}$$

Assuming X_{it} is discrete in this example. Also, as T approaches infinity, they calculate the low cutting of the outlined set. Non-separability and weaker suppositions on non-observed U_{it} in (Chernozhukov and Hansen, 2008) make their model far more general than **Eq. 1**. However, the following conditions are satisfied are less robust, and the estimators are more sophisticated. Specifically, this research contributed in two ways to the literature.

RESULTS

In the first part of this section, we applied the TOPSIS to measure all variables' overall efficiency in this dataset. Here, the indicators are divided into two different segments: positive indicators and negative type indicators. This work's novelty is that we have added a fiscal predictor for the first time to view its impact on environmental conditions via R&D expenditures and green energy projects.

The positive indicators are mentioned and summed up in **Table 1**. Indonesia is the largest country with a per capita GDP, trailed by the Philippines and Vietnam, from countries in Southeast Asia. India leads the side in South Asian countries, followed by Bangladesh and Pakistan. Here is a considerable gap in GDP per capita between South and Southeast Asian economies. However, the condition of renewable energy sources is much different. South Asian economies lead the side as India generates 217899ktoe of renewable energy source followed by 144726 of Indonesia of Southeast Asian County. Again, the expenditure on R&D is the percentage of total GDP, Bangladesh spending 3.13 percent of total GDP followed by second South Asian country (India) with 0.65 percent. Here the overall expenditure in the field of R&D as a percentage of GDP in South and Southeast Asian economies is deficient, which could be the fundamental reason for their late conversion towards green energy projects.

According to **Figure 1**, even though the GDP per capita performance is much better in the Southeast Asin region, their contribution in renewable energy production is minimal concerning South Asian economies whose renewable energy sources contribute better than Southeast Asian economies. The main difference between these two differences could be the expenditure in R&D. South Asians spend much more percentage of their GDP in R&D compared to Southeast Asian economies. Here, we can see that overall R&D expenditure in R&D as a percentage of GDP in renewable energy is deficient compared to developed economies. It is straightforward that these economies do have not sustainable economic conditions, and they must do debt financing for the developed world to meet their day-to-day expenditures. Therefore, they spend much less on R&D in renewable energy projects.

According to **Table 2** of cost type indicators, Indonesia has the highest air and GHG emission per capita (7.04 tonnes), followed by another Southeast Asian country, Vietnam (2.15 tonnes). India holds the third position with 1.85 tonnes of Air and GHG emission in this line; however, it keeps the first air pollution effects with 469.05 (Million HAB). Here, Indonesia holds the second position in air pollution effects with 431.49 (Million HAB).

To overcome air and GHG and environmental degradation, it needs intensive money for economic, R&D, and technological innovations. However, these developing economies prefer to meet their necessary expenditures. Due to high fiscal imbalance, they must pay tremendous money to developed economies' interest rates or principles.

Table 3 shows considerable fluctuations in the underline indicators in both regions after including the fiscal indicators in the TOPSIS index. It may happen due to inconsistent economic and fiscal policies. Due to fiscal deficit and high dependency on international financial institutions, most countries perform averagely in renewable energy production, R&D in renewable energy projects, economic progress, and sustainable environmental conditions.

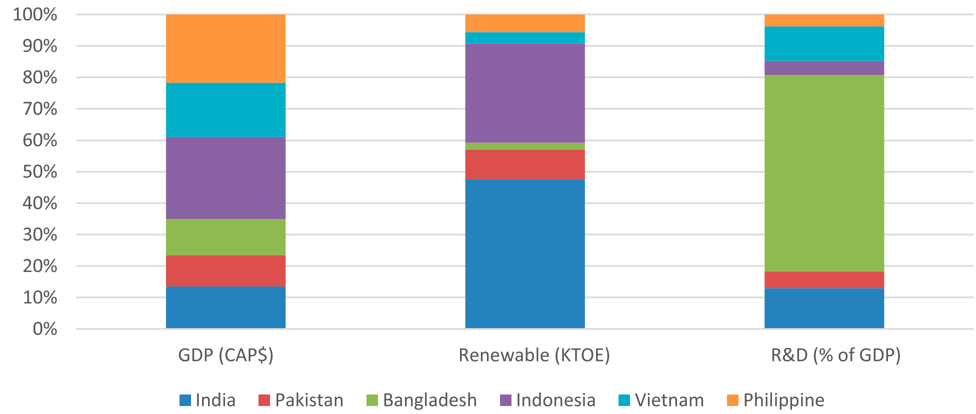

FIGURE 1 | Performance of selected South-East developing economies.

TABLE 2 | Scores of negative indicators in South-East Asia.

	Air and GHG emission (TONNE_CAP)	Air pollution effects (million HAB)
India	1.85	469.05
Pakistan	0.99	363.12
Bangladesh	0.68	380.05
Indonesia	7.04	431.49
Vietnam	2.15	364.33
Philippine	0.69	363.82

Figure 2 shows the overall performance of underline economies in the TOPSIS method. According to the outcomes, the Philippines attained the highest position in TOPSIS index performance with a 0.63 score, followed by India with 0.61. Vietnam is third in line with a 0.60 score. Indonesia and Pakistan secure the fourth position with 0.67, while Bangladesh is the low-performance country in this data set with a 0.54 score. Here, the overall TOPSIS index conditions are deplorable as not a single country could attain a high score between 0.90–1, which could be ideal in this regard. We can also see that all these South and Southeast Asian economies' average score is 0.58, respectively.

This average TOPSIS index score shows that fiscal indicators have a multidimensional impact on R&D, green energy projects, and economic growth. The more stable an economy, the higher the expenditure on R&D, and the higher the output of R&D in the form of green energy project completion.

Considering the above outcomes, this study expends empirical analysis by applying the QARDL technique to verify the outcomes' composite index results and robustness. The consequences of the QARDL research are presented as under:

TABLE 3 | TOPSIS score.

Year	India	Pakistan	Bangladesh	Indonesia	Vietnam	Philippine
2000	0.57	0.62	0.60	0.79	0.81	0.75
2001	0.61	0.64	0.59	0.78	0.84	0.73
2002	0.81	0.75	0.77	0.66	0.53	0.57
2003	0.84	0.81	0.74	0.61	0.68	0.74
2004	0.89	0.77	0.87	0.79	0.69	0.55
2005	0.91	0.79	0.84	0.81	0.71	0.96
2006	0.89	0.93	0.81	0.98	0.81	0.93
2007	0.19	0.23	0.28	0.41	0.47	0.61
2008	0.39	0.31	0.15	0.42	0.43	0.58
2009	0.64	0.43	0.21	0.39	0.53	0.65
2010	0.24	0.35	0.37	0.25	0.27	0.24
2011	0.42	0.42	0.35	0.22	0.34	0.21
2012	0.41	0.31	0.29	0.22	0.33	0.58
2013	0.28	0.3	0.24	0.41	0.45	0.52
2014	0.61	0.51	0.51	0.29	0.47	0.48
2015	0.53	0.34	0.37	0.36	0.63	0.35
2016	0.61	0.7	0.87	0.91	0.87	0.93
2017	0.88	0.87	0.78	0.8	0.84	0.89
2018	0.92	0.79	0.73	0.98	0.90	0.81
2019	0.90	0.77	0.72	0.89	0.90	0.91
2020	0.89	0.80	0.79	0.90	0.91	0.92

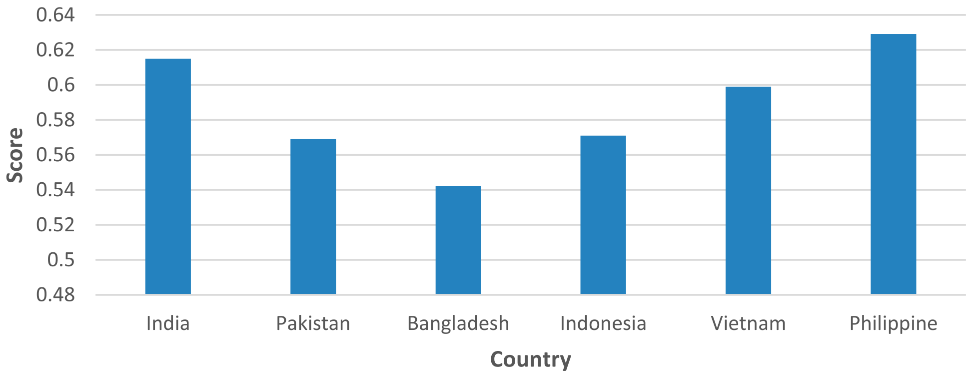

FIGURE 2 | TOPSIS score.

TABLE 4 | Unit root test results and statistics summary.

Variable	ECO	FIL	ENG	ENV
Mean	13.95	−5.65	5.09	4.00
Minimum	11.37	24.54	10.01	7.04
Maximum	16.33	−33.62	0.83	0.52
S.Deviation	0.96	8.43	3.64	2.08
JarqueeBera	7.24	16.44	8.48	10.85
Prob	(0.002)	(0.003)	(0.003)	(0.004)
ADF (Level)	−2.45	−2.33	−1.45	−1.33
ADF (D)	−5.44***	−6.34***	−5.41***	−5.34***
ZA (Level)	−3.12	−3.01	−2.75	−2.66
ZA (D)	−7.77***	−9.77***	−11.21***	−6.77***

Denotes a 1 percent significance level.

TABLE 5 | Correlation matrix.

	ECO	FIL	ENG	ENV
ECO	1			
FIL	−0.393	1		
ENG	−0.380	0.144	1	
ENV	−0.335	0.231	0.305	1

Table 4 presents the statistical summary of the underlined variables and their results of a unit root.

Table 5 shows the correlation matrix of the variable. According to the outcomes, there is no correlation among the variables.

The OLS and Quantile Estimates values appear in **Table 6**. This research demonstrated that the energy coefficient was statistically significant and adversely influenced the calculation. The coefficient signs for "ENG" are consistent; it shows a strong association statistically with the dependent component (i.e., environment or ENV). QARDL performances also support the results of long-term estimates based on the ARDL model. The findings have shown that research and development technical advancements in renewable energy play an essential role in environmental quality and control of its deterioration.

Diagnostic inspections have been carried out through Wald and Bound tests in the **Table 7**. According to these statistics, the measured F-statistic is quantitatively more significant than the upper and lower limits of the distribution. It implies that economic complexity and energy use clearly correlate to impacts on the environment. Statisticians in Wald reject the

TABLE 6 | OLS and quantile estimation results.

Parameter	POLS	Quantile regression								
		10th	20th	30th	40th	50th	60th	70th	80th	90th
ECO	0.89***	0.04*	0.09***	0.01	0.09***	0.09***	0.10***	0.09***	0.10***	0.08**
	(0.03)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01	(0.02)	(0.02)	(0.03)
FIL	0.97**	0.64*	0.01***	0.69***	0.16***	0.70***	0.17***	0.75***	0.31	0.77***
	(0.05)	(0.07)	(0.02)	(0.01)	(0.02)	(0.05)	(0.01	(0.07)	(0.28)	(0.07)
ENG	−0.99*	0.27	−1.08***	−0.20	−0.56***	−0.82***	−0.69***	−0.82***	−0.29***	−0.83***
	(0.06)	(0.27)	(0.05)	(0.26)	(0.04)	(0.02)	(0.05	(0.02)	(0.02)	(0.02)
ENV	0.97***	0.60*	0.85***	0.60***	1.59***	0.59**	0.77***	0.59***	0.89**	0.77***
	(0.04)	(0.05)	(0.02)	(0.01)	(0.05)	(0.05)	(0.02	(0.05)	(0.05)	(0.02)
Constant	8.81***	8.60**	9.10***	5.12***	22.10**	9.01**	11.096**	22.02**	9.89***	13.15**
	(0.02)	(0.05)	(0.02)	(0.01)	(0.05)	(0.05)	(0.05)	(0.05)	(0.03)	(0.05)

, **, * show the 10, 5, and 1% level of significance respectively.*

TABLE 7 | Diagnostic inspections with Wald & Bound tests.

Wald test for equality of slopes

	Quantile			
	First	**Second**	**Third**	**Fourth**
10–50th	25–50th	75–50th	90–50th	
ECO	0.983***	0.030***	0.691***	0.661***
FIL	0.083*	0.073**	0.081**	0.091*
ENG	0.030**	0.088*	0.072*	0.063**
ENV	0.462	0.098*	0.019**	0.091***

Bounds test for Linear ARDL

	10%		5%		1%		Probability	
	I(0)	**(1)**	**I(0)**	**(1)**	**I(0)**	**(1)**	**I(0)**	**(1)**
F	2.751	4.561	3.258	5.643	3.762	5.132	0.071	0.085
T	−2.931	−3.615	−4.159	−6.734	−4.125	−5.245	0.036	0.056

, **, * show the 10, 5, and 1% level of significance respectively.*

null hypothesis of term and cointegration for error correction substantially. It indicates that CO_2 emissions are not linear with economic complexity and energy use in South and Southeast Asia. The tests of Wald test and Levene suggest that investigators have received sufficient evidence to reject the zero-constancy hypothesis. Based on the results obtained from the Wald test, the null hypothesis is rejected since it is significant in long and short periods for the co-integrated heteroskedasticity set factors.

DISCUSSION

The TOPSIS results indicate that countries of both the regions (South and Southeast) are suffering to attain a high index score based on benefit and cost type analysis. The average score of South and Southeast Asian economies is around 50% which is considered very poor regarding sustainable development and the environment. It could be due to low R&D expenditures, low renewable energy projects, high fiscal imbalance, and inconsistent economic growth.

In these societies, fiscal hedging has a harmful impact on environmental degeneration, based on the empirical findings of QARDL. Results reveal that the higher the amount of fiscal shelter in these economies, the more significant the deterioration in the environment and the lower it is for SDG achievement. These results are also consistent with (Liao et al., 2019) on the empirical review of Guangdong's province using panels of 21 cities from 2000 to 2016 and (Wen and Dai, 2020) for China's environmental and fiscal imbalances during 1990–2016. Thus, global leaders devoted their resources, time, and money to emphasize the relevance of fiscal imbalance in SDGs.

The study evidence of technical innovations is also positively influencing a sustainable future. Hence, technological advances towards emission-free energy and production help develop the Asian economies towards the Sustainable Development Goals. Empirically, technical advances in renewable energy may contribute to sustainable environmental circumstances through sustainable growth. This research evidence matches the studies of (Ashin and Muhammed, 2020; Cerdeira Bento and Moutinho, 2016). It is a question of supporting and involving investment and policy, regulatory, R&D, and other partners. By assessing their accomplishments, utilizing their skills, and setting their constraints, economies can enhance their competitive advantages and benefit from recommended practice as modernization principals at all revenue stages by emerging nations. Technical improvements enable a longer-term planning process for a more permanent organization. One of the main economic difficulties lies in the exchange between sustainability and the economy. Globally, we confront the significant damage to the environment and technology to solve this issue.

The energy contribution index in the sustainable environment procedure is favourable. Here, as the more R&D (GDP percentage) funding for energy production, the more sustainable the South-Southeast Asian economies will be. The inclusive green economy is the path to sustainable development (Iram et al., 2019; Baloch et al., 2020). studies indicated that more excellent net value of research and development to foster renewable energy businesses or innovations would result in sustainable performance. At the same time, (Iqbal et al., 2019) experimentally demonstrated that only green and highly effective economic and environmental imbalances could be solved. It shows that the more liberalized the financial sector, the greater the capacity for developing Asian countries to safeguard the environment under the SDG standards. Thus, financial competence is quite essential in sustainable growth and environmental preservation.

A fundamental correlation existed here between sustainable use of energy, innovation, and economic growth. Our research suggests that the economic development of renewable energy through R&D through the financial and technical improvements has a significant and good effect on non-carbon and green energy production. It promotes energy supply strategies to encourage a cohesive energy supply and long-term economic development (Omri, 2014). In this respect, too, a durable balance is proven between the real GDP, the consumption of renewables, and the short-term bi-directions between renewable energy use and economic growth (Apergis and Payne, 2010). The practical usage of renewable energy sources is suggested to be of low expertise.

The inadequacy of funding for incorporating clean energy in the energy mix might also be related. Dual links between clean energy usage and economic progress may also exist. Monetary support is needed as clean energy can be used by the wealthiest nations (Ntanos et al., 2018). Moreover, the outcomes of the country-specified studies show that several of this research varied from energy usage to economic development (Ozturk, 2010). This research highlights the benefits of government measures, such as renewable energy growth tax credits and renewable energy.

CONCLUSION

This study evaluates fiscal imbalances, renewable energy R&D, and technologies in a carbon-free energy economy for sustainable development. To this goal, four independent indices were recognized: the financial index, the energy index, the fiscal index, and the environmental index, predicated on the South and South Asia economy data for 18 years. The findings are significant because of the worry of economic expansion changing economic issues and environmental changes in developing economies. The composite index results show that the performance level in South and South-East Asia is terrible in renewable energy, fiscal imbalances, R&D spending, and environmental conditions. All these nations have a composite index score of approximately 50 percent.

The outcomes of the QARDL technique demonstrate that human capital makes an enormous and beneficial contribution to the carbon-free economy of the South and Southeast nations. Due to fiscal hedging, the SDG goal has become very hard to achieve. The research suggests that the technological improvement of renewable energy through R&D helps decrease greenhouse gas and accelerates the development process. Renewable energies are the critical factors of sustainable climate in emerging Asian economies. Increased R&D spending in traditional and green energy technology, reduced greenhouse gas emissions through cleaner energy trends and energy quality gains. Reduced greenhouse gases are therefore crucial in terms of global warming.

Policy Implication

Fiscal hedging is an effective indicator of sustainable development for green energy production and consumption. Countries with a high fiscal imbalance hold low R&D in energy and renewable energy projects.

- The climate change issue is not related to a single country or region. So, there is a need for a collective effort in the form of money, time, and expertise. Countries already suffering from fiscal imbalance will never fulfil their sustainable environment commitments. Therefore, developed economies and financial institutions should help these economies work for a sustainable environment and development.
- A crucial part of a sustainable environment is green energy. Controlling climate change is a significant aspect of improving environmental quality. Therefore, the transformation of green technological innovation in these developing countries is critical. Thus, the role of developed economies in sustainable developing economies is significant.
- Enable and encourage beneficiaries of public and private sector breakthroughs to leverage environmentally friendly innovations.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

Conceptualization, done by LC; methodology, form by SA; software and validation, performed by CT; formal analysis did by RK; investigation, resources, data curation, performed by WY; writing—original draft preparation done by FG; writing-review and editing by LC; visualization, and supervision by RK.

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APPENDIX 1

Variable name	Abbreviation	Data source
Gross Domestic Product	GDP	WDI
Research and Development	R&D	WDI
Fiscal index	ECO	WDI
Financial index	FIL	IMF
Energy index	ENG	IEA
Environmental index	ENV	IEA

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A Measurement and Analysis of the Growth of Urban Green Total Factor Productivity——Based on the Perspective of Energy and Land Elements

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From the perspective of input and output differentiation, using the SBM directional distance function method and Luenberger productivity index, this paper calculates the index of the green total factor productivity (GTFP) growth of 280 cities in China, from 2004 to 2016. This study also analyzes the growth sources of urban GTFP and the decomposition situation of GTFP in four cases, as well as the factors that affect the growth of GTFP. Finally, the following conclusions are drawn: 1) the overall growth trend of GTFP under four different situations of elements input is basically consistent. As a whole, the growth trend can be divided into three stages. The first rising stage of GTFP growth was from 2004 to 2008; the next declining stage was from 2008 to 2012, and a further rising stage occurred from 2012 to 2016. 2) From the decomposition situation of GTFP growth, we can know that the main source of GTFP growth is in the scale efficiency (LSEC) of GTFP. The decomposition of inefficiency levels in four cases shows that the inefficiency of land resources is the highest among many factors. Land resource inefficiency is also the key factor determining the output efficiency; the input inefficiency and bad-output inefficiency between them account for about 50% of the overall inefficiency level. 3) Among the factors that influence GTFP growth, the negative effect of urban land and energy structure is mainly reflected in the pure technology growth (LPTP) and scale efficiency growth (LSEC) of GTFP. In addition, investment in scientific and technological innovation and foreign direct investment both have a significantly positive effect on GTFP growth, as well as in improving urban population density and road area per capita.

Keywords: green total factor productivity growth, Luenberger productivity index, decomposition of GTFP growth, influencing factors of GTFP growth, measurement and analysis

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INTRODUCTION

Energy has become an important factor affecting the improvement of economic efficiency and high-quality development of China's economy. In fact, during the 11th Five-Year Plan period (2005–2010), China's energy consumption per unit GDP actually decreased by 19.3%. The actual decline was 18.4% during the 12th Five-Year Plan period (2010–2015), and the ratio of energy consumption per unit GDP decreased by 11.4% from 2015 to 2018, during the 13th Five-Year

Plan period. Energy consumption has decreased more than before, but it is still one of the important factors that cannot be ignored in the process of high-quality economic development (970 million tons of coal, 49.18 million tons of crude oil, and 53.3 billion cubic meters of natural gas were produced in China in the first quarter of 2021, based on *National Bureau of Statistics* data).

At the same time, the rapid development of urbanization in China has caused urban land resources to be a core element of economic development. By the end of 2018, the number of Chinese cities had reached 672 (297 prefecture-level cities; 375 county-level cities). The urbanization rate of permanent residents reached 59.58% (48.94% higher than in 1949); at the end of 1978, there were 193 cities (101 prefecture-level cities; 92 county-level cities). During this period, specifically from 1981 to 2017, the urban built-up area in China increased from 7,438 km^2 to 56,225 km^2, an increase of nearly 660%, based on data from the *National Bureau of Statistics in China*.

The rapid growth and high-quality development of China's economy have also been closely related to the process of market-oriented reform (Cai, 2018; Liu, 2018) and the degree of market resource allocation (Nie and Jia, 2011). However, existing research on resource allocation focuses more on capital elements (Chen et al., 2019; Wu and Lin, 2016; Fang, 2007) and human capital elements (Li and Yin, 2017; Yuan and Xie, 2011; Lai and Ji, 2015), as well as on the matching degree of capital and labor (Hsieh and Klenow, 2009). Some studies have focused on the allocation of resources for the agricultural (Elahi et al., 2021a; Elahi et al., 2021b), industrial sectors (Zhao et al., 2021; Sun et al., 2021c; Pei et al., 2020), energy efficiency (Sun et al., 2021a; Zhang et al., 2021), or socio-economic viability of solar commercialization and electrification (Sun et al., 2021a) and the effect of technological innovation and knowledge spillover on energy efficiency (Sun et al., 2021b). But only a few scholars have put energy factors into a production function model in the overall analysis of resource allocation efficiency (Wang et al., 2010; Chen and Chen, 2017; Watanabe and Tanaka, 2007; Sun et al., 2021c), mostly focus on labor, capital, technology, and other factors (Wang et al., 2006; Cai and Fu, 2017). Therefore, this paper will mainly focus on the effect of energy and land resource factors on the green total factor productivity (GTFP) when considering capital, labor, energy and land factors (K/L/E/S), as well as considering the environment factors, which is different from traditional productivity analyses that only consider capital and labor (K/L).

As for the measurement of GTFP, the global SBM directional distance function is the mainstream method used to measure productivity (Tone, 2001; Fukuyama and Weber, 2009; Yang et al., 2019). Yang et al. (2019) measured using the Malmquist-Luenberger index (Fare et al., 1994; Chung and Fare, 1995), based on the non-radial slack SBM direction distance function (Tone, 2001). The index was then decomposed into an efficiency change index (ML-EFFCH) and technology change index (ML-TECH). Many scholars have used the Malmquist-Luenberger index (Chung and Fare, 1995) to measure the green total factor productivity in the United States (Fare et al., 2001), OECD countries, Asia (Jeon & Sickles, 2004), Taiwan Province (Yu et al., 2008), OPEC countries (Wang et al., 2008) and China (Kaneko and Managi, 2004; Managi and Kaneko, 2006; Yang and Shao, 2009; Chen, 2010).

Liu et al. (2016) calculated the GTFP and its decomposition value based on the DEA-Malmquist productivity index. The study took SO2 and COD emissions as environmental bad output factors. Chen (2016) calculated the industrial GTFP by using the SBM directional distance function and ML index. Wang et al. (2010) analyzed and decomposed the GTFP using the SBM directional distance function and Luenberger productivity index. The study found that excessive energy consumption and excessive emissions of SO2 and COD would lead to environmental inefficiency. Dong et al. (2012) measured the source of industrial GTFP by using slack efficiency loss and the Luenberger productivity index. The study found that both labor technology progress (Li and An, 2012) and pollution control (Wang and Sheng, 2015) can effectively improve industrial GTFP. Kuang and Peng (2012), using the Malmquist index combined with stochastic frontier function in a VRS case, found that GTFP can reflect environmental efficiency loss and resource utilization efficiency differences. Cui and Zhang (2014) measured China's agricultural environmental efficiency and agricultural green total factor productivity, as well as their changes, based on the principle of material conservation. The results showed that environmental efficiency can reflect the utilization efficiency and material absorption efficiency of various factors in agricultural production.

In the process of measuring GTFP, environmental factors must be included in the input-output production function. These factors may accurately measure the loss of efficiency of resources. Some scholars regard energy as an environmental resource input (Chen and Chen, 2017; Watanabe and Tanaka, 2007; Tone, 2001; Fukuyama and Weber, 2009; Yang and Shao, 2009). Some scholars also divide "good output" and "bad output" in resource output to measure the influence of environmental factors. The measurement of bad output is usually set by three industrial wastes, namely industrial waste gas, smoke and water emissions (Cheng and Li, 2009; Hu et al., 2008; Wu, 2010; Kaneko and Managi, 2004; Managi and Kaneko, 2006). Others only use SO2 emissions (TuWatanabe and Tanaka, 2007; TuWatanabe and Tanaka, 2008), or add COD based on the former (Managi and Kaneko, 2006; Hu et al., 2008; Wang et al., 2010), or CO_2 emissions (Yang et al., 2019).

Based on the above analysis, the main contributions of this paper are as follows: Firstly, this paper will mainly focus on the effect of energy and land resource factors on the green total factor productivity (GTFP) when considering capital, labor, energy and land factor (K/L/E/S), which is different from traditional productivity analyses that only consider capital and labor (K/L). Secondly, using the method of SBM directional distance function and Luenberger productivity index from the perspective of resource input-output differentiation, it calculates the index of the GTFP growth of 280 cities in China from 2004 to 2016, and analyzes the growth sources of urban GTFP and the decomposition situation of GTFP in four cases. Thirdly, the study also conducts an inefficiency level analysis of input inefficiency (IE_x), "good" output (IE_y) and "bad" output inefficiency (IE_b), and analyzes the factors that influence the growth of GTFP, which is the key to high-quality economic growth.

THEORETICAL ANALYSIS

The measurement and theoretic analysis of GTFP is mainly based on the Solow economic growth model or its related production function model. The traditional Solow economic growth model mainly covers two production factors: labor (L) and capital (K). The model's production function is Y=F (A, K, L), which can be further simplified to Y=F (K, AL); AL represents effective labor. Romer (2001) further expanded the model in the book Advanced Macroeconomics, adding natural resources and land resources to the production function, and using the C-D production function model as follows:

$$Y = K^{\alpha}R^{\beta}T^{\gamma}[A, L]^{1-\alpha-\beta-\gamma}\ ,\ \alpha>0\ ,\ \beta>0\ ,\ \gamma>0\ ,\ \alpha+\beta+\gamma<1 \tag{1}$$

In the above formula, K represents capital stock, R represents available resources, T represents available land resources, and α, β, and γ represent corresponding capital elasticity, resource elasticity and land elasticity, respectively. It is also assumed that the scale effect remains unchanged. Next, A and L represent knowledge capital and labor. However, the model only exists in the theoretical analysis level, without any actual measurement analysis.

In the process of studying economic growth and the allocation of resource elements, some scholars consider adding energy elements into the basic AK model Y=F (K, AL), in order to study the phenomenon of total factor productivity or resource mismatch (Pang, 2009; Wang et al., 2010; Yang et al., 2015; Chen and Chen, 2017; Yang et al., 2019). Among them, Chen and Chen (2017) put energy elements into the production function framework and analyzed the total energy elements covering time, industry and region.

The function is set as follows:

$$Y_{ij} = A_{ij}\left(K_{ij}^{\alpha i}L_{ij}^{\beta i}E_{ij}^{1-\alpha i-\beta i}\right)^{\varnothing} \tag{2}$$

where i and j represent different regions and industry sectors; ∅ indicates scale effect, and A_{ij}, K_{ij}, L_{ij}, E_{ij} represent total factor productivity, capital, labor and energy input, respectively.

In this paper, the influence of energy and land factors on the growth of total factor productivity is considered in the model construction. In addition, referring to Brandt's model construction ideas (Brandt et al., 2013), the growth and change of GTFP in China are analyzed from the allocation efficiency perspective of incorporating energy (E) and land resources (S). Therefore, the theoretical analysis model of this paper is set as follows:

$$Y_i = A_i\left(K_i^{\alpha i}L_i^{\beta i}E_i^{\gamma i}S_i^{1-\alpha i-\beta i-\gamma i}\right)^{\varnothing} \tag{3}$$

In the above, i represents different urban areas, E represents the amount of energy used, S represents the land resources used, and α, β and γ represent the corresponding elasticity and scale effect. Next, Y_i represents the total output GDP of region i, and Y represents the total output at the national level. The production function at the national level (Brandt et al., 2013) is as follows:

$$Y = \left(\sum_{i=1}^{N}\omega_i Y_i^{1-\theta}\right)^{\frac{1}{1-\theta}} \tag{4}$$

where, ω_i is the weighted weight of regional output GDP, and θ measures the elasticity factor of output substitution between regions. Then, the formulas of total factor productivity A_i and A at urban level and national level are as follows:

$$A_i = \frac{Y_i}{\left(K_i^{\alpha i}L_i^{\beta i}E_i^{\gamma i}S_i^{1-\alpha i-\beta i-\gamma i}\right)^{\varnothing}}$$

$$A = \frac{Y}{\left(K^{\alpha}L^{\beta}E^{\gamma}S^{1-\alpha-\beta-\gamma}\right)^{\varnothing}} = \frac{\left(\sum_{i=1}^{N}\omega_i Y_i^{1-\theta}\right)^{\frac{1}{1-\theta}}}{\left(K^{\alpha}L^{\beta}E^{\gamma}S^{1-\alpha-\beta-\gamma}\right)^{\varnothing}}$$

$$= \left(\sum_{i=1}^{N}\omega_i\left(k_i^{\alpha i}l_i^{\beta i}e_i^{\gamma i}s_i^{1-\alpha i-\beta i-\gamma i}\right)^{\varnothing(1-\theta)}\right)^{\frac{1}{1-\theta}} \tag{5}$$

Then, $k_i = \frac{K_i}{K}, l_i = \frac{L_i}{L}, e_i = \frac{E_i}{E}, s_i = \frac{S_i}{S}$ and satisfy the following conditions:

$$\sum_{i=1}^{N}L_i = L, \sum_{i=1}^{N}K_i = K, \sum_{i=1}^{N}E_i = E, \sum_{i=1}^{N}S_i = S \tag{6}$$

As the optimal conditions for maximizing output are: $k_i = l_i = e_i = s_i = \pi_i$, the optimal environmental factor productivity A^* can be obtained by combining the above **Formula (5)** as follows:

$$A^* = \left(\sum_{i=1}^{N}\omega_i(\pi_i)^{\varnothing(1-\theta)}\right)^{\frac{1}{1-\theta}} \tag{7}$$

Then, according to the optimal condition $\frac{S_i}{S} = \frac{K_i}{K} = \frac{L_i}{L} = \frac{E_i}{E} = \pi_i$, the following formula is obtained:

$$\pi_i = \frac{\omega_i^{\frac{1}{\theta}}A_i^{*\frac{1-\theta}{\theta}}}{\sum_{i=1}^{n}\omega_i^{\frac{1}{\theta}}A_i^{*\frac{1-\theta}{\theta}}} \tag{8}$$

Then:

$$A^* = \left(\sum_{i=1}^{N}\omega_i^{\frac{1}{\theta}}A_i^{*\frac{1-\theta}{\theta}}\right)^{\frac{1}{(1-\theta)\varnothing}} \tag{9}$$

Then, the efficiency loss d of resource allocation is obtained:

$$D = \ln(A^*/A) \text{or} D_i = \ln\left(A_i^*/A_i\right) \tag{10}$$

$$D = \ln\left(\frac{A^*}{A}\right) = \ln\left(\frac{\left(\sum_{i=1}^{N}\omega_i(\pi_i)^{\varnothing(1-\theta)}\right)^{\frac{1}{1-\theta}}}{\left(\sum_{i=1}^{N}\omega_i(\mu_i)^{\varnothing(1-\theta)}\right)^{\frac{1}{1-\theta}}}\right) \tag{11}$$

According to the above analysis, if the energy factor E and land factor S are ignored in A_i ($A_i = \frac{Y_i}{(K_i^{\alpha i}L_i^{\beta i}E_i^{\gamma i}S_i^{1-\alpha i-\beta i-\gamma i})^{\varnothing}}$), then the factor productivity A_i^{-E-S} ($A_i^{-E-S} = \frac{Y_i}{(K_i^{\alpha i}L_i^{1-\alpha i})^{\varnothing}}$) can be obtained. There is

TABLE 1 | nergy conversion coefficient.

Energy Name	Converted Heat Coefficient	Conversion Standard Coal Coefficient
LPG	50,179 kJ/kg	1.7143 kg standard coal/kg
Natural gas	32,238–38,931 kJ/m^3	1.1000–1.3300 kg standard coal/m^3
Power	3600 kJ/kWh (kwh)	0.1229 kg standard coal/kwh

Note: The data come from the energy conversion coefficient table in the China Energy Statistics Yearbook 2018*, The average value is calculated when converting natural gas, which is 35,584.5 kJ/m3 and 1.2150 kg standard coal/m3, of which 1 t = 1,000 kg.*

also a big difference with the actual value A_i, and the equilibrium condition $k_i = l_i = e_i = s_i = \pi_i$ can hardly be satisfied. The equilibrium condition that can hardly be satisfied is core, which may cause an error between the actual environmental factor productivity $A = (\sum_{i=1}^{N} \omega_i (\mu_i)^{\varnothing(1-\theta)})^{\frac{1}{1-\theta}}$ and the ideal environmental productivity level $A^* = (\sum_{i=1}^{N} \omega_i (\pi_i)^{\varnothing(1-\theta)})^{\frac{1}{1-\theta}}$. The essence of their error lies in the fact that μ_i and π_i satisfy different conditions.Where $\mu_i = k_i^{\alpha i} l_i^{\beta i} e_i^{\gamma i} s_i^{1-\alpha i-\beta i-\gamma i}$ (realistic conditions).Where $\pi_i = k_i^{\alpha i} l_i^{\beta i} e_i^{\gamma i} s_i^{1-\alpha i-\beta i-\gamma i}$ and $\pi_i = \frac{S_i}{S} = \frac{K_i}{K} = \frac{L_i}{L} = \frac{E_i}{E}$ (ideal conditions).

The two conditions need to be met at the same time in ideal conditions, and the realistic conditions only need to meet the first condition. In addition, the process of resource allocation is to make the ratio of various resources infinitely close to the ideal condition π_i. Considering the factor resources (capital, labor, energy and land), which have a great influence on economic growth, the analysis results are not only able to avoid some defects of the previous AK model (only labor and capital), but the contribution of various factors (such as energy and land) to economic growth in real economic development are also analyzed. As such, the results have both theoretical and practical significance.

RESEARCH DESIGN AND DATA DESCRIPTION

The data of this paper come from the *Statistical Database of China Economic Network* and the 《*database of the development research center of the State Council*. In this paper, the SBM directional distance function and Luenberger productivity indicator are used to measure the GTFP of 280 cities in China, from 2004 to 2016. The production input element and the "good" output elements (for desirable outputs) and "bad" output elements (for undesirable outputs) should also be considered simultaneously (Wang et al., 2010; Yang et al., 2019; Chambers et al., 1996; Caves et al., 1982; Grosskopf, 2003; Yuan and Li, 2018). The factor input in this paper covers four production factors (capital, labor, energy, and land, or K/L/E/S). Outputs include "good" outputs (GDP) and "bad" outputs (three types of industrial waste), with specific indicators as follows: 1) Capital input: capital investment in urban fixed assets investment (unit: 10,000 yuan); 2) Labor input: the number of employees in the city at the end of the year (unit: 10,000 people); 3) Energy input: In the calculation process of total factor productivity, it is necessary to consider energy input. In this paper, the main energy consumption in the city is summed up, and the main energy consumption indexes are the consumption of urban liquefied petroleum gas, natural gas and electricity. Then, according to the conversion coefficient in **Table 1**, the heat data (KJ) and standard coal (kg) data are obtained. The heat data (KJ) is used as the energy input index, and then the standard coal (kg) input is used as an alternative variable to test the reliability of the index; 4) Land resources input: The urban construction land area can better reflect the supply status of land resources elements in market economy activities and conform to the land's characteristics as a factor of production. Therefore, the investment of land resources elements is measured by urban construction area (unit: km^2); 5) Good output: Good output (also referred to as desirable output) mainly uses industrial added value (Tu, 2008; Yang et al., 2019) or regional GDP (Managi and Kaneko, 2006; Wang et al., 2010). This paper takes cities as the basic unit, so good output is measured by urban GDP (unit: 10,000 yuan); 6) Bad output: The indicators of bad output (also referred to as undesirable output) in this paper are industrial waste gas SO_2 (Unit: t), industrial smoke dust (Unit: t) and industrial wastewater discharge (unit: 10,000 t). These three indicators are the main indicators used to measure objects of bad output in the production process (Kaneko and Managi, 2004; Managi and Kaneko, 2006; Hu et al., 2008; Cheng and Li, 2009; Wu, 2010). The data are also relatively complete.

In this paper, every city (with a city as the basic unit) is set as a production decision-making unit (DMU) to construct the production practice boundary. Because different resource elements (labor L, capital K, land S and energy E) need to be incorporated into the production decision-making behavior, it is necessary to construct the environmental factor input (EI), environmental "good" output and "bad" output, including the city K and period T, in the model setting.

In the model, it is assumed that city K uses N kinds of elements as inputs X, $\mathbf{X} = (x_1, x_2, x_3, \cdots x_N) \in R_N^+$, and produces M kinds of "good" outputs Y, $\mathbf{Y} = (y_1, y_2, y_3, \cdots y_M) \in R_N^+$, as well as I types of "good" outputs B, $B = (b_1, b_2, b_3, \cdots b_I) \in R_N^+$. The input and output set of city K are $(x^{t,k}, y^{t,k}, b^{t,k})$, when the corresponding production possibility set meets the basic assumptions (Tone, 2001; Tone, 2002; Fare et al., 2007; Wang et al., 2008; Fare and Grosskopf, 2010). The DEA data envelopment method is used to set the model as follows:

$$P^t(x^t) = (y^t, b^t): \left\{ \begin{array}{l} \sum_{k=1}^{K} z_k^t y_{km}^t \geq y_{k'm}^t,\ \forall m \\ \sum_{k=1}^{K} z_k^t x_{kn}^t \geq x_{k'n}^t, \forall n \\ \sum_{k=1}^{K} z_k^t b_{ki}^t \geq b_{k'i}^t,\ \forall i \\ \sum_{k=1}^{K} z_k^t = 1, z_k^t \geq 0, \forall k \end{array} \right\} \quad (12)$$

where z_k^t represents the weight of each cross-sectional observation of the model. If $\sum_{k=1}^{K} z_k^t = 1$ and $z_k^t \geq 0 \geq 0$, this means that the production technology is variable return on scale (VRS). If $z_k^t \geq 0$, this means constant return on scale (CRS). This paper assumes VRS in the production process.

In this paper, the global SBM directional distance function (Tone, 2002; Fukuyama and Weber, 2009; Wang et al., 2010; Yang et al., 2019) is used; the specific method is as follows:

$$S_V^G\left(x^{t,k}, y^{t,k}, b^{t,k}, g^x, g^y, g^b\right) = max_{s^x s^y s^b} \frac{\frac{1}{N}\sum_{n=1}^{N}\frac{s_n^x}{g_n^x} + \frac{1}{M+I}\left(\sum_{m=1}^{M}\frac{s_m^y}{g_m^y} + \sum_{i=1}^{I}\frac{s_i^b}{g_i^b}\right)}{2} \quad (13)$$

$$\text{s. t.} \sum_{t=1}^{T}\sum_{k=1}^{k} z_k^t x_{kn}^t + s_n^x = x_{k'n}^t,\ \forall n;\ \sum_{t=1}^{T}\sum_{k=1}^{k} z_k^t y_{km}^t - s_m^y = y_{k'm}^t, \forall m$$

$$s.\ t. \sum_{t=1}^{T}\sum_{k=1}^{k} z_k^t b_{ki}^t - s_i^b = b_{k'i}^t, \forall i$$

$$s.\ t. \sum_{k=1}^{K} z_k^t = 1, z_k^t \geq 0, \forall k; s_n^x \geq 0, \forall n; s_m^y \geq 0, \forall m; s_i^b \geq 0, \forall i$$

In the above, $x^{t,k}$, $y^{t,k}$, and$b^{t,k}$, respectively, represent the input of resource elements, "good" output and "bad" output of city K in T period. Then, g^x, g^y, and g^b, respectively, represent the direction vectors of input reduction, "good" output increase, and "bad" output decrease. Finally, s_n^x, s_m^y, and s_i^b, respectively, represent the slack vectors of input, "good" output and "bad" output; that is, the quantities of excessive input, insufficient "good" output and excessive "bad" output. If s_n^x, s_m^y, s_i^b are all positive, this means that the actual input s_n^x is greater than the boundary input, the actual good output s_m^y is less than the boundary output, and the actual bad output s_i^b is greater than the boundary output (Wang et al., 2010; Yang et al., 2015; Yang et al., 2019).

When the direction vector (g^x, g^y, g^b) and the slack vector (s_n^x, s_m^y, s_i^b) have the same measurement unit, the standardized slack ratio can be added up, and the objective function is to maximize the sum maximization of the average value of input inefficiency and output inefficiency (Fukuyama and Weber, 2009). Following the ideas of Wang et al. (2010) and Cooper et al. (2007), this paper divides the inefficiency (IE) into three parts (IE_x, IE_y, **and**IE_b), which is a high and low index reflecting the level of inefficiency.

The inefficiency of the input: $IE_x = \frac{1}{2N}\sum_{i=1}^{N}\frac{s_n^x}{g_n^x}$.

The inefficiency of "good" output (for desirable outputs): $IE_y = \frac{1}{2N}\sum_{i=1}^{N}\frac{s_m^y}{g_m^y}$.

The inefficiency of "bad" output (for undesirable outputs): $IE_b = \frac{1}{2N}\sum_{i=1}^{N}\frac{s_i^b}{g_i^b}$.

According to the above method, the inefficiency index of production activities in 280 cities in China, from 2004 to 2016, is calculated in a directional distance function measure, and the 2003 data is the base period data.

The Luenberger productivity index (Chambers et al., 1996) and the Malmquist productivity index (Caves et al., 1982) are applied in different disciplines. Together, they form a Malmquist Luenberger index (ML index) (Chung and Fare, 1995) in the process of development. A Luenberger productivity index is the general form of the M index and ML index, and the specific Luenberger model (Chambers et al., 1996; Wang et al., 2010) is as follows:

$$GTFP_t^{t+1} = \frac{1}{2}\{[S_C^t(x^t, y^t, b^t: g) - S_C^t(x^{t+1}, y^{t+1}, b^{t+1}: g)] + [S_C^{t+1}(x^t, y^t, b^t: g) - S_C^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}: g)]\} \quad (14)$$

Then, according to the idea of Grosskopf (2003), the specific Luenberger model is divided into four parts (Fare et al., 1994; Fare et al., 2007; Wang et al., 2010; Yuan and Li, 2018), which are pure efficiency change (LPEC), pure technology change (LPTP), scale efficiency change (LSEC) and technology pure scale change (LTPSC), as follows:

$$LPEC_t^{t+1} = \frac{1}{2}\{[S_V^t(x^t, y^t, b^t: g) - S_V^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}: g)]\} \quad (15)$$

$$LPTP_t^{t+1} = \frac{1}{2}\{[S_V^{t+1}(x^t, y^t, b^t: g) - S_V^t(x^t, y^t, b^t: g)] + [S_C^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}: g) - S_C^t(x^{t+1}, y^{t+1}, b^{t+1}: g)]\} \quad (16)$$

$$LSEC_t^{t+1} = \frac{1}{2}\{[S_C^t(x^t, y^t, b^t: g) - S_V^t(x^t, y^t, b^t: g)] - [S_C^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}: g) - S_V^t(x^{t+1}, y^{t+1}, b^{t+1}: g)]\} \quad (17)$$

$$LTPSC_t^{t+1} = \frac{1}{2}\left\{\left[(S_C^{t+1}(x^t, y^t, b^t: g) - S_V^{t+1}(x^t, y^t, b^t: g)) - (S_C^t(x^t, y^t, b^t: g) - S_V^t(x^t, y^t, b^t: g))\right] + \left[(S_C^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}: g) - S_V^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}: g)) - (S_C^t(x^{t+1}, y^{t+1}, b^{t+1}: g) - S_V^t(x^{t+1}, y^{t+1}, b^{t+1}: g))\right]\right\} \quad (18)$$

$$\text{GTFP} = \text{LPEC} + \text{LPTP} + \text{LSEC} + \text{LTPSC} \quad (19)$$

In the above, if GTFP, LPEC, LPTP, LSEC and LTPSC are greater than (or less than) 0, that indicates that productivity increases (declines), efficiency improves (deteriorates), technology progresses (declines), scale efficiency increases (declines), and technology deviates from CRS.

EMPIRICAL ANALYSIS

Table 2 lists the decomposition status of inefficiency levels in four cases (K/L; K/L/S; K/L/E, and K/L/S/E). In the input inefficiency (IE_x), the highest level of input inefficiency is 0.204 in the second case (K/L/S), from 2004 to 2016; the IE_x is lower than 0.200 in other

TABLE 2 | Results of inefficiency level decomposition.

Efficiency	Input Inefficiency IEx				"Good" output Inefficiency IEy				"Bad" output Inefficiency IEb			
Element	K/L	K/L/S	K/L/E	K/L/S/E	K/L	K/L/S	K/L/E	K/L/S/E	K/L	K/L/S	K/LE	K/L/S/E
2004	0.237	0.232	0.223	0.226	0.118	0.243	0.002	0.015	0.241	0.243	0.237	0.234
2005	0.252	0.234	0.231	0.221	0.008	0.241	0.002	0.011	0.251	0.241	0.241	0.233
2006	0.216	0.241	0.202	0.221	0.001	0.256	0.000	0.004	0.268	0.256	0.250	0.244
2007	0.209	0.234	0.196	0.216	0.003	0.257	0.000	0.004	0.268	0.257	0.257	0.247
2008	0.205	0.222	0.205	0.216	0.004	0.257	0.001	0.003	0.280	0.257	0.260	0.247
2009	0.210	0.224	0.224	0.239	0.005	0.250	0.001	0.011	0.278	0.250	0.271	0.256
2010	0.211	0.213	0.188	0.205	0.006	0.244	0.001	0.006	0.271	0.244	0.266	0.246
2011	0.191	0.212	0.161	0.191	0.005	0.239	0.000	0.004	0.258	0.239	0.261	0.240
2012	0.178	0.197	0.167	0.189	0.010	0.225	0.001	0.007	0.235	0.225	0.234	0.227
2013	0.158	0.157	0.142	0.142	0.008	0.213	0.001	0.002	0.217	0.213	0.230	0.223
2014	0.179	0.150	0.163	0.148	0.005	0.223	0.001	0.002	0.216	0.223	0.226	0.224
2015	0.174	0.174	0.184	0.185	0.004	0.222	0.001	0.004	0.229	0.222	0.223	0.214
2016	0.157	0.162	0.154	0.169	0.003	0.220	0.001	0.003	0.222	0.220	0.217	0.207
overall	0.198	0.204	0.188	0.198	0.006	0.238	0.001	0.006	0.249	0.238	0.244	0.234

Note: The above-mentioned factor types are divided into four categories. In the first case, the factor inputs are only capital and labor elements (K/L). In the second case, the inputs are capital, labor, and land elements (K/L/S). The inputs in the third case are capital, labor, and energy elements (K/L/E), and in the fourth case, the capital, labor, land and energy elements are included (K/L/S/E).

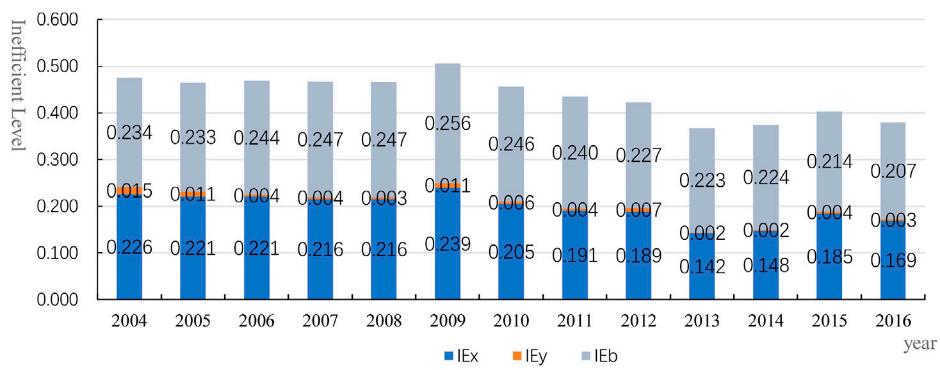

FIGURE 1 | Inefficiency levels in fourth case (K/L/S/E) when the capital, labor, land and energy elements are all included.

cases (the IE_x in the other three cases are 0.198, 0.188 and 0.198, respectively). The results are also same when the input inefficiency is divided into different years. This finding shows that the inefficiency level of land resources is the highest among many factors. In addition, the input inefficiency in the first case (K/L) is consistent with the fourth case (K/L/S/E), but there are some slight differences in different years.

In the "good" output inefficiency (IE_y), the inefficiency level in the second case (K/L/S) is higher than 0.200 when the land elements are included. The overall level of the 2004–2016 period is 0.238, while the inefficiency level in other cases is basically lower than 0.010. The average difference between the inefficiency levels is nearly 40 times (the difference between 0.238 and 0.006). This finding shows that the land factor is the key factor in determining the "good" output efficiency. Meanwhile, the level of energy factor inefficiency is in the decline channel, and the level is low; the average level of inefficiency is only 0.001.

In the "bad" output inefficiency (IE_b), the inefficiency levels in different situations (from 2004 to 2016) are close to 0.240 (the four cases of inefficiency levels are 0.249, 0.23, 0.244 and 0.234, respectively). According to the data of different years in three parts (IE_x, IE_y, andIE_b), the inefficiency level is neither accurate nor in line with reality when only capital and labor factors are taken into accounts (first case: K/L). This finding indicates that it is more realistic to consider the elements of energy and land in the production model.

For better analysis on the proportional relationship between the three inefficiency levels (IE_x, IE_y, andIE_b), **Figure 1** shows the relationship between the three inefficiency levels when the capital, labor, land and energy elements are all included (K/L/S/E). The columnar proportional graph of the three inefficiencies shows that the inefficiency level of good output (IE_y) is low, accounting for only 3.16%, while input inefficiency IE_x and bad output inefficiency IE_b all account for about 50% of the overall inefficiency level. Therefore, in the process of improving production efficiency and GTFP, the key objects to be considered are the inefficiency of input IE_x and the inefficiency of output IE_b.

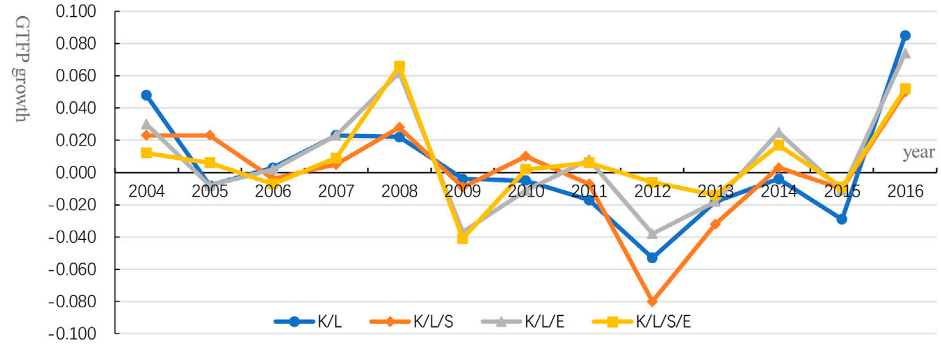

FIGURE 2 | GTFP growth in four cases (K/L; K/L/S; K/L/E; K/L/S/E).

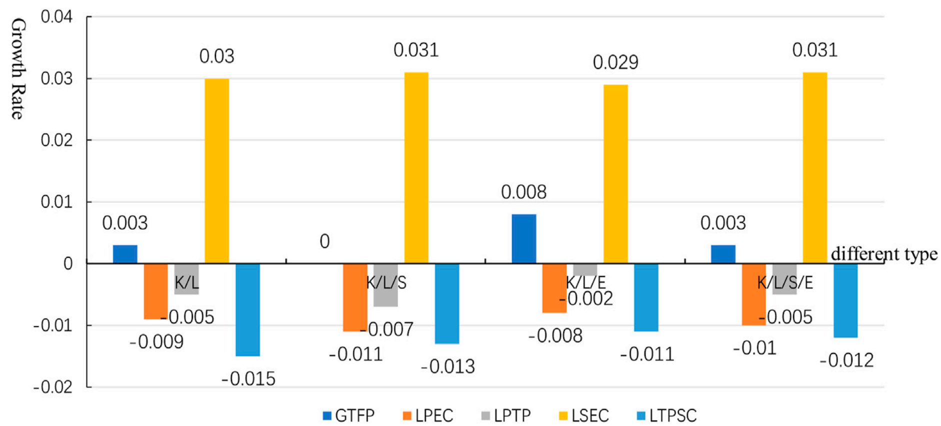

FIGURE 3 | Growth rate and decomposition results of overall GTFP in four cases (K/L; K/L/S; K/L/E; K/L/S/E).

Figure 2 shows the growth of GTFP under four cases (K/L; K/L/S; K/L/E; K/L/S/E). The overall growth trend of GTFP under different situations is basically consistent, and the trend can be divided into three stages as a whole. Specifically, the GTFP growth rate during 2004–2008 was in a rising stage. From 2008 to 2012, the GTFP growth rate was in a declining stage. The GTFP growth rate in 2012–2016 was in a further rising stage. However, in general terms regarding the positive and negative growth rate of GTFP, the rate was positive in the 2004–2008 period, negative in 2009–2015, and positive after 2015.

From 2004 to 2008, the GTFP showed an overall growth trend and a positive value. This was closely related to the opening up of China's economy and the reform of the domestic market economy (*reform and opening up in 1978; market economy reform in the 1990s; China joined the WTO in 2001*), which accelerated the transformation and development of China's economic structure and improved the country's environmental and economic efficiency. The negative growth rate of GTFP from 2008 to 2015 shows that the "three high effects" of economic structure were prominent (high input, high consumption and high pollution in the production process). The inefficiency of some enterprises with backward production capacity significantly reduced the ecological environment efficiency in urban areas and accelerated the process of environmental pollution and the waste of resources. However, the negative growth trend of the growth rate weakened and began to move towards a positive growth trend in 2012. This changing trend indicated that the effects of environmental protection policies (such as eco-environmental protection, pollution control, waste gas treatment, environmental regulation, waste recovery systems, etc.) began to appear. Then, the production process began to pay more attention to eco-economic concepts, such as low carbon, environmental protection, energy saving, resource saving technological innovation, and harmony between man and nature.

Figure 3 shows the decomposition of the overall GTFP from 2004 to 2016, under four different factor input cases. The four kinds of decomposition results correspond to the overall productivity growth (GTFP). The four kinds of decomposition results are pure efficiency growth (LPEC), pure technology growth (LPTP), scale efficiency growth (LSEC) and technology pure scale growth (LTPSC), which occur in the process of GTFP growth. As can be seen from **Figure 3**, the GTFP and its decomposition are similar in a growing trend on the whole, but there are some differences in the four different type cases. The GTFP growth rate is the lowest when the land factor is included (second case: K/L/S), and therefore, the land resource factor is the main factor limiting the overall growth of GTFP.

TABLE 3 | Decomposition of GTFP growth.

Decomposition	Only Capital and Labor Factors (first case: K/L)				Capital, Labor, land and energy Elements (Fourth case: K/L/S/E)			
	LPEC	LPTP	LSEC	LTPSC	LPEC	LPTP	LSEC	LTPSC
2004	0.007	−0.003	0.034	0.005	−0.015	−0.007	0.033	−0.001
2005	−0.035	−0.005	0.076	−0.046	−0.009	−0.008	0.023	−0.002
2006	−0.004	−0.006	0.029	−0.018	−0.007	−0.010	0.017	−0.004
2007	0.006	−0.004	0.028	−0.011	−0.003	−0.010	0.036	−0.016
2008	0.002	−0.003	0.024	−0.004	0.034	0.004	0.081	−0.051
2009	−0.001	−0.002	−0.006	0.005	−0.044	−0.005	−0.024	0.034
2010	−0.026	−0.003	0.054	−0.033	−0.016	−0.003	0.042	−0.020
2011	−0.021	−0.001	0.071	−0.061	−0.006	0.004	0.042	−0.029
2012	−0.039	−0.008	0.034	−0.039	−0.052	−0.009	0.046	−0.044
2013	0.014	−0.009	−0.035	0.005	0.003	−0.011	0.001	−0.005
2014	0.010	−0.010	0.009	−0.018	0.027	−0.007	0.019	−0.018
2015	−0.031	−0.012	0.012	−0.001	−0.022	−0.008	0.030	−0.007
2016	0.004	−0.002	0.067	0.018	−0.020	0.000	0.061	0.011
overall	−0.009	−0.005	0.030	−0.015	−0.010	−0.005	0.031	−0.012

Note: The data in the table are pure efficiency change (LPEC), pure technology change (LPTP), scale efficiency change (LSEC) and technology scale change (LTPSC), respectively; also, GTFP = LPEC + LPTP + LSEC + LTPSC.

TABLE 4 | GTFP growth and its decomposition in the fourth case (K/L/S/E).

Resolve	GTFP		LPEC		LPTP		LSEC		LTPSC	
Type	Kj	Kg	Kj	Kg	Kj	Kg	Kj	Kg	Kj	Kg
2004	0.012	0.011	−0.015	−0.015	−0.007	−0.008	0.033	0.029	−0.001	0.002
2005	0.006	0.004	−0.009	−0.009	−0.008	−0.009	0.023	0.024	−0.002	−0.003
2006	−0.007	−0.006	−0.007	−0.007	−0.010	−0.010	0.017	0.020	−0.004	−0.003
2007	0.009	0.005	−0.003	−0.004	−0.010	−0.011	0.036	0.036	−0.016	−0.017
2008	0.066	0.064	0.034	0.034	0.004	0.002	0.081	0.077	−0.051	−0.049
2009	−0.041	−0.046	−0.044	−0.046	−0.005	−0.009	−0.024	−0.024	0.034	0.032
2010	0.002	0.002	−0.016	−0.014	−0.003	−0.002	0.042	0.039	−0.020	−0.021
2011	0.006	0.004	−0.006	−0.008	0.004	0.003	0.042	0.040	−0.029	−0.032
2012	−0.066	−0.071	−0.052	−0.052	−0.009	−0.013	0.046	0.047	−0.044	−0.050
2013	−0.014	−0.015	0.003	0.004	−0.011	−0.011	0.001	−0.005	−0.005	−0.008
2014	0.017	0.017	0.027	0.029	−0.007	−0.009	0.019	0.017	−0.018	−0.025
2015	−0.009	−0.006	−0.022	−0.021	−0.008	−0.009	0.030	0.017	−0.007	0.002
2016	0.052	0.046	−0.020	−0.022	0.000	0.002	0.061	0.048	0.011	0.019
total	0.003	0.001	−0.010	−0.010	−0.005	−0.007	0.031	0.028	−0.012	−0.012

Note: KJ, in the table indicates that heat input is used in the process of energy input; kg indicates that standard coal is used in the process of energy input.

In the decomposition of the GTFP growth rate, only LSEC is significantly positive. Pure efficiency growth (LPEC), pure technology growth (LPTP) and technology scale growth (LTPSC) are all significantly negative, indicating that the main source of the green total factor growth rate lies in scale efficiency (LSEC). Meanwhile, pure efficiency, pure technology and technology scale are significantly reducing the overall level of green environment total factor productivity. Taking the fourth case (K/L/S/E) as an example, the scale efficiency growth (LSEC) reaches 0.031; the absolute value is nearly three times that of the pure efficiency growth (LPEC), the value of which is -0.010. Also, pure technology growth (LPTP) is -0.005, and technology scale growth (LTPSC) is -0.012.

The results in **Table 3** show the growth decomposition results of GTFP in different years. The overall decomposition results in two cases are close, and the differences between different growth decomposition types are small. Compared with the first case (K/L), in the fourth case (K/L/S/E), the average value of LPEC is about 0.001 lower than the first case (-0.009 and -0.010 respectively). The average value of LPTP is all -0.005, and the average value of LSEC in the fourth case is 0.001 higher (0.030 and 0.031, respectively). Also, the technology scale growth (LTPSC) is about 0.003 higher (-0.015 and -0.012, respectively), indicating that scale effect is the main source of GTFP growth. In addition, the technology scale (LTPSC) has the greatest negative impact on growth, while scale efficiency (LSEC) has the greatest positive impact. **Table 4** shows the decomposition results by using different energy accounting methods. The results are close, similar and robust.

ANALYSIS OF THE INFLUENCING FACTORS OF GTFP GROWTH

The above has analyzed the growth process and decomposition situation of GTFP. Next, this study will deeply explore the core

TABLE 5 | Definition of variables in Function 20.

Variable	Variable symbol	Definition
The explained variable	GTFP	The growth of green total factor productivity
	LPEC	Change of pure efficiency in GTFP.
	LPTP	Change of pure technology in GTFP.
	LSEC	Change of scale efficiency in GTFP.
	LPTSC	Change of technology scale in GTFP.
The explained variable	Energy _struct	The ratio of electricity consumption to urban energy consumption (urban liquefied petroleum gas, natural gas and electricity consumption)
	Land _struct	The ratio (%) of urban construction land area to urban area, used to reflect the land supply situation
The control variable	lnGRP	GRP: urban per capita GDP.
	lnSCIF	SCIF: investment in urban innovation expenditure on scientific undertakings
	lnFDI	FDI: foreign direct investment
	lnQ	Q: urban population density
	lnW	W: road area per owned by urban settlements

TABLE 6 | Analysis of factors influencing the growth of green total factor productivity.

Variables	(1)	(2)	(3)	(4)	(5)
	GTFP	LPEC	LPTP	LSEC	LTPSC
Land-struct	−0.0016***	-0.0002	−0.0023***	−0.0015*	−0.0014
	(−3.258)	(−0.491)	(−3.654)	(−1.826)	(−1.270)
Energy-struct	−0.0401*	0.0100	−0.0088	−0.0299	0.0201
	(−1.796)	(0.590)	(−0.311)	(−0.842)	(0.415)
lnscif	0.0190***	0.0053**	0.0053	−0.0001	0.0029
	(5.342)	(1.979)	(1.183)	(-0.010)	(0.376)
lnfdi	0.0023*	0.0008	−0.0009	−0.0025	−0.0007
	(1.877)	(0.855)	(−0.571)	(−1.275)	(−0.268)
lnq	0.0212***	0.0009	0.0289***	0.0200**	0.0156
	(3.901)	(0.207)	(4.184)	(2.315)	(1.321)
lnw	0.0191***	0.0032	0.0177**	0.0131	0.0177
	(2.781)	(0.605)	(2.031)	(1.204)	(1.188)
lngrp	−0.0027	−0.0200***	−0.0056	0.0135	−0.0048
	(−0.341)	(−3.289)	(−0.556)	(1.064)	(−0.274)
Constant	−0.2853***	0.1630**	−0.1755	−0.2428	−0.1195
	(-2.785)	(2.097)	(−1.352)	(−1.493)	(−0.539)
Observations	3,640	3,640	3,640	3,640	3,640
R-squared	0.041	0.004	0.008	0.003	0.001
Number of time	13	13	13	13	13

Note: According to the results of the Hausman test, this paper adopts the panel model of bidirectional fixed panel effect; some data are processed by logarithm.

factors that affect the growth of GTFP and will analyze the mechanism and process related to GTFP growth. The model of influencing factor analysis is set as follows:

$$GTFP_{it} = \alpha + \beta_0 Energy\_struct_{it} + \beta_1 Land\_struct_{it} + \beta_2 lnGRP_{it} + \beta_3 lnSCIF_{it} + \beta_4 lnFDI_{it} + \beta_5 lnQ_{it} + \beta_6 lnw_{it} + \mu_t + \pi_i + \varepsilon_{it} \tag{20}$$

The explained variable ($GTFP_{it}$) is the growth rate of GTFP in the fourth case (K/L/S/E), and the other explained variables are LPEC, LPTP, LSEC and LPTSC. Here, i represents different cities, t represents different years, $\mu_t, \pi_i,$ **and**ε_{it} represent time effect, regional effect and random effect, respectively. And the error term (εit) is normally distributed with zero mean value and constant variance (Elahi et al., 2019; Elahi et al., 2020).

Definition of variables in Function 20 are shown in **Table 5**. The analysis results of influencing factors are shown in **Table 6**. As a whole, the greater the proportion of the land construction area is in an urban area, the lower the utilization efficiency of land resources is; the corresponding growth ability of GTFP is also weakened. The overall negative effect is significant at 1% level (the coefficient is -0.0016). This is mainly reflected in pure technology change LPTP (the coefficient is -0.0023) and scale efficiency change LPEC (the coefficient is -0.0015). The overall negative effect of urban energy consumption structure on GTFP growth is significant (the coefficient is -0.0401), but the positive effect on pure efficiency growth (LPEC) and technology scale growth (LTPSC) is not significant. Negative effects are mainly reflected in pure technology change (LPTP) and scale efficiency change (LSEC), but the effect is not significant. This finding shows that no scale effect exists when electricity is the core of energy consumption; the improvement of energy efficiency is also not obvious.

In addition, a 1% growth in innovation investment of local fiscal expenditure on scientific undertakings will promote the growth of GTFP by 0.0190 as a whole. This is mainly due to the increase of LPEC on GTFP (the coefficient is 0.0053). This finding indicates that investment in scientific and technological innovation can improve the production process and production efficiency of enterprises, and then enhance the growth of GTFP. Foreign direct investment has a positive effect on GTFP growth (the coefficient is 0.0023), which shows that foreign investment can bring about a significant improvement in production efficiency. The overall efficiency promotion effect is also higher than that of the "pollution paradise effect". In addition, for a 1% growth in urban population density and road area per unit owned by urban settlements, the growth effects on GTFP are 0.0212 and 0.0191, respectively.

CONLCUSIONS AND POLICY RECOMMENDATIONS

From the perspective of resource input-output differentiation, the growth index of green total factor productivity (GTFP) of 280 cities in China, from 2004 to 2016, is calculated by using SBM directional distance function and the Luenberger productivity index. This study also analyzes the growth of urban GTFP and the decomposition situation of overall GTFP in four cases, as well as the factors that affect GTFP growth. The following conclusions are drawn:

1) The overall growth trend of GTFP under four different situations is basically consistent and can be divided into three stages. The growth rate of GTFP during the years from 2004 to 2008 was in a rising stage. From 2008 to 2012, the GTFP growth rate was in a declining stage, and the GTFP growth rate in the years from 2012 to 2016 was in a further rising stage. From the decomposition of GTFP growth, the main source of growth was the scale efficiency (LSEC) growth of GTFP. Meanwhile, there were negative growth effects in pure efficiency change (LPEC), pure technology change (LPTP), and technology scale change (LTPSC). (2)The columnar proportional graph of the three inefficiencies (IE_x, IE_y and IE_b) shows that the inefficiency level of good output (IE_y) is low; input inefficiency (IE_x) and bad output inefficiency (IE_b) between them account for about 50% of the overall inefficiency level. The decomposition status of inefficiency levels in four cases (K/L; K/L/S; K/L/E; K/L/S/E) shows that the inefficiency level of land resources is the highest among many factors. Land factor is also the key factor in determining good output efficiency. The overall levels of bad output inefficiency (IE_b) in different situations are relatively close. (3) Among the factors that influence GTFP growth, the negative effect of land resources supply structure is mainly reflected in pure technology growth (LPTP) and scale efficiency growth (LSEC). The negative effect of urban energy structure is also mainly reflected in LPTP and LSEC but is not significant. In addition, investment in scientific and technological innovation and foreign direct investment have a significantly positive effect on GTFP growth, as well as in improving urban population density and road area per capita.

According to the above analysis, the policy recommendations of this paper are as follows:

Firstly, from the perspectives of factor input and output, the key to improving the growth of GTFP is to reduce “inefficient factor input” and “ineffective bad output”. The realization path of reducing “inefficient factor input” lies in reasonably optimizing the proportion allocation structure of production factors, realizing the best ratio of factors and maximizing marginal production efficiency. The way to reduce the “inefficiency of bad output” lies in changing the production processes and industrial structure of enterprises, adopting advanced production technology and manufacturing processes, eliminating backward industrial forms and manufacturing processes, and realizing clean, harmless and environmentally-friendly production and manufacturing, as well as in maximizing output and minimizing environmental external effects. Secondly, from the source and decomposition process of GTFP growth, the growth of scale efficiency (LSEC) is the main source of GTFP growth. Therefore, more attention should be paid to the scale effect of market and the agglomeration effect of manufacturing in provincial capital cities, coastal open cities, and coastal industrial parks. Efforts should also be made to maximize the scale effect of market economic groups and to effectively improve the quality and environmental efficiency of economic growth. At the same time, technical factors are also at the core of limiting GTFP growth. A need exists to focus on the research and development of environmentally-friendly production technology and on the transformation and optimization of production processes. These steps should be taken to effectively improve the growth potential of GTFP and eco-environmental efficiency in production and manufacturing links. Thirdly, among the factors that influence GTFP growth, more attention should be paid to the production efficiency and allocation efficiency of energy and land factors. The key to high-quality economic growth lies in improving the growth elasticity of energy factors, reducing the energy consumption ratio per unit GDP, and reducing the consumption of non-renewable energy, such as fossil and coal. In addition, the proportion of clean energy, such as hydropower, solar energy, wind energy and nuclear energy in the total energy consumption should be increased, so as to improve environmental economic efficiency from the pattern of resource consumption. At the same time, the inefficient and low-efficient use of land resources is also a factor limiting economic growth. Therefore, rationally adjusting the market supply ratio of land resources, and fully guaranteeing the sustainable and efficient use of land resources is important. These steps could effectively improve the circulation efficiency and use efficiency of limited land resources, and avoid the idle and inefficient allocation of land resources.

Recommendations for future study is that we need to more focus on the policy of clean energy, the policy of low carbon city construction, as well as the environmental governance policy, etc. To analysis the policy effect on environmentally-friendly production and manufacturing, pollution discharge, and eco-economic efficiency for high quality development in the future.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

Both authors contributed to the writing, review and editing of the manuscript.

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A Spatial Empirical Examination of the Relationship Between Agglomeration and Green Total-Factor Productivity in the Context of the Carbon Emission Peak

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We aim to explore the impact of economic agglomeration on the development of green total-factor productivity (GTFP) from both theoretical and empirical levels. We use the non-radial directional distance function method to formulate the GTFP index and further empirically study the impact of economic agglomeration on GTFP. The results indicate that: 1) there is a "U-shaped" curve relationship between economic agglomeration and GTFP, and the formation mechanism is that the economic agglomeration has a threshold effect on the agglomeration externalities such as infrastructure sharing, knowledge spillover, and labor market upgrading. 2) The mismatch of industrial structure is an important reason that the economic agglomeration in this region has not produced an obvious spatial spillover effect on other regions; relaxing restrictions on the concentration of economic activity to regional centers would contribute to the improvement of GTFP. 3) GTFP has the classic "snowball effect" in the time dimension but has the obvious "warning effect" in the space and time dimension. The conclusions of the research show that it is necessary to conform to the redistribution of economic geography, promote the rational allocation of human resources in the territorial space, and promote the coordination of economic agglomeration and green economic development goals.

Keywords: green total factor productivity, economic agglomeration, dynamic spatial dupin model, spatial spillover, employment density

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1 INTRODUCTION

In 2015, 193 UN member states formally adopted the outcome document "Transforming Our World: The 2030 Agenda for Sustainable Development" at the Sustainable Development Summit. The programmatic document, covering 17 Sustainable Development Goals (SDGs), aims to advance three ambitious global goals, one of which is to protect the environment and curb climate change. The 2030 Agenda for Sustainable Development is a major improvement over the Millennium Development Goals. Its implementation will mobilize countries around the world to effectively integrate the SDGs into the national development strategies. Environmental goals have become a pillar of sustainable development as important as social and economic goals. The growing importance of environmental factors in the global development agenda makes green economic development an important part of sustainable development.

With the increasingly prominent global environmental problems, environmental protection has gradually become the consensus of all the countries. The unanimous agreement of nearly 200 parties to the United Nations Framework Convention on Climate Change to adopt the Paris Agreement is good proof. But the developed and developing countries face different situations. By enhancing the intensity of environmental regulation, the developed countries develop green technologies and promote green production and gradually transfer the polluting industries abroad, thereby continuously improving environmental quality. For the developing countries, despite the rapid economic growth, the environmental quality is deteriorating. However, there are still doubts about whether the intensity of environmental regulation should be increased. The main reason is the concern that the raising environmental regulations may be detrimental to sustainable economic growth. Therefore, exploring how to achieve the synergy of environmental protection, resource conservation, and economic growth has become an important academic topic.

At present, the global response to climate change is unprecedentedly urgent. To combat climate change, reduce the total amount of greenhouse gas emissions, mainly carbon dioxide (CO_2), 37 countries, including China, have formally committed to carbon neutrality by incorporating national laws, submitting agreements or policy declarations. As the country with the largest total CO_2 emissions in the world, China pledged in September 2020 to strive to achieve carbon peaking by 2030 and carbon neutrality by 2060. But this is undoubtedly a huge challenge. China is facing a trade-off between energy consumption, CO_2 emissions, and economic growth.

China's economic construction has made great achievements, but it has paid a serious price as well. China's GDP currently ranks second in the world. At the same time, however, carbon dioxide emissions rank first in the world. In addition, China has become the world's largest energy consumer since 2009. The Chinese government is paying more and more attention to environmental issues and has made a series of institutional arrangements. After China first proposed the binding energy-saving indicators in the "11th 5-Year Plan", in 2009, for the first time, it proposed an action target of reducing carbon emissions per unit of GDP by 40–45% compared with 2005. China's "12th 5-Year Plan" and "13th 5-Year Plan" have also successively put forward binding energy intensity and carbon emission intensity control targets. The proposal of energy saving and emission reduction targets not only poses challenges for China's future economic development but also becomes an important opportunity for China's economic green transformation.

In the process of China's rapid economic development, the economic agglomeration has become another typical empirical fact. Cities have become major areas of economic activity and major sources of CO_2 emissions, accounting for about 85% of China's total CO_2 emissions. This also leads this study to ask the following question: Is the agglomeration of economic activities the key source of increased regional energy consumption and environmental damage? It requires rigorous normative analysis and robust empirical testing to provide a scientific answer to this question. Therefore, based on the consideration of the abovementioned practical problems, this article will systematically examine the relationship between economic agglomeration and green economic development from both the theoretical and empirical levels. This article is important because the achievement of the global SDGs cannot be achieved without China's contribution. This is because China is the second-largest economy in the world and also because China is the world's largest CO_2 emitter and energy consumer. The conclusions of this article have vital important implications for China and the world to achieve the SDGs.

The rest of this article is organized as follows: **Section 2** presents a review of the literature on agglomeration and green economy, **Section 3** provides the theoretical analysis, **Section 4** describes the empirical methods and data resource, **Section 5** presents the empirical results and discussions, and **Section 6** offers the conclusion.

2 LITERATURE REVIEW

The rise of urban agglomerations has aroused scholars' attention to the phenomenon of economic agglomeration. Some scholars believe that economic agglomeration is conducive to improving the efficiency of production factors, which can make the factors better match between the supply side and demand side to save production costs (Pierre et al., 2012). It can also reduce the transportation cost per unit distance by sharing the regional infrastructure (Daniel, 2007). In addition, it has positive effects such as sharing knowledge spillover (Greenstone et al., 2010) and an advanced labor market (Ines, 2020).

However, some scholars believe that economic agglomeration, as a compact spatial economic behavior, will not only bring about the expansion of the output scale but also increase the energy consumption and pollutant emission. Furthermore, the increased discharge of the industrial and domestic wastewater will lead to lack of clean drinking water, and the excessive emission of soot and sulfur dioxide will lead to the deterioration of air quality. It harms the healthy and sustainable development of urban agglomeration and greatly limits the international competitiveness of the city. Taking Chinese cities as research samples, some scholars have listed empirical evidence of environmental decline caused by the concentration of economic activities (Sun & Yuan, 2015; Liu et al., 2017; Wang et al., 2020; Lan et al., 2021). In particular, Cheng (2016) incorporated the spatial effect into the model species and concluded that the agglomeration would aggravate the local and adjacent environmental deterioration. Liu et al. (2017) considered both the time lag effect and spatial effect and found that agglomeration was an important factor causing environmental pollution. Chen et al. (2017) investigated the impact of economic agglomeration on the environmental quality from a micro perspective and found that the spatial concentration of enterprises and economic activities would aggravate the carbon dioxide emission in the agglomeration area. According to the conclusions of the existing literature, economic agglomeration may cause the target cities to face serious resource and environmental problems, which is closely related to the current green economic development transition in China.

In the context of "carbon peak", seeking an effective way to support the development of a green economy has become a hot issue of concern to all the countries. As the world's second-largest economy and the largest primary energy consumer, it is undoubtedly a huge challenge for China to achieve resource conservation and environmental improvement, while achieving economic growth. Solving China's problems well will provide "Chinese wisdom" and "Chinese solutions" for the countries around the world to achieve green economic transformation and development.

The existing literature provides abundant evidence for understanding the effects of economic agglomeration on the economic growth and environmental pollution, but it is worth emphasizing that these studies have neglected the comprehensive effects of the agglomeration on both. In this article, "green total-factor productivity", a comprehensive index considering economic growth, resource conservation, and environmental protection, is selected as the explained variable to explore the impact of economic agglomeration on green development. Second, we argue that the inconsistent conclusions about the direction of economic agglomeration's influence on the development of the green economy may be due to the inconsistency of endogenous problems caused by reverse causality. Finally, in the existing related research, few works of literature consider the spatial correlation of variables. We argue that neglecting the regional spatial correlation may lead to bias in the conclusion.

Compared with the existing studies, the possible marginal contributions of this study are as follows. First, we expand the research framework for the analysis of the influencing factors of the green TFP from the perspective of labor and economic activity agglomeration. The synergy between agglomeration and green economic development is an important perspective to understand the transformation of the economic development model. However, the existing literature mainly considers the impact of FDI (Li M. et al., 2019), market structure (Lin and Chen, 2018), environmental regulation (Wang et al., 2018), and technological progress (Ying et al., 2021) on the green TFP. It ignores the important role that economic agglomeration may play. Second, we expand the production density model of Ciccone & Hall (1996), taking into account the spatial correlation caused by labor mobility and agglomeration externalities. Furthermore, we provide reliable empirical support for understanding the important role of economic agglomeration in the process of transition to "sustainable development".

3 THEORY

Some related studies represented by Ciccone & Hall (1996) systematically explained the positive externalities of agglomeration using the production density function. This provides a good idea for us to explore the mechanism of green TFP promotion from the perspective of economic agglomeration. However, the production density model does not consider the regional spatial correlation caused by labor mobility and agglomeration externalities. In this article, we will further introduce spatial interaction into the production density model to derive some theoretical predictions that may be useful for future empirical studies. The production function of the representative city is set as follows:

$$q_i = A\left(l^{\beta}k^{1-\beta-\gamma}e^{\gamma}\right)^{\alpha}(Q_i/S_i)^{\frac{\lambda-1}{\lambda}}, \tag{1}$$

where q_i is the output per unit land area of the city i, Q is the total output, S is the total land area of the city, and A refers to the efficiency of economic output that simultaneously considers labor, capital, energy, expected output, and nonexpected output in the production activities, namely, green TFP. L, k, and e, respectively, represent the number of labor, physical capital, and energy input per unit land area. α [$\alpha\in(0,1)$] is the return of the factor input per unit area. β and γ [β, $\gamma\in(0,1)$] represent the output elasticity of the labor and resources, respectively. λ is the density coefficient ($\lambda > 1$), and $(\lambda-1)/\lambda$ is the externality of agglomeration. The larger the λ, the stronger is the positive externality of economic agglomeration.

Assuming that the input elements are evenly distributed on the land of each city, the total output of the city (i) can be expressed as follows:

$$\begin{aligned} Q_i &= q_iS_i = A\left(l^{\beta}k^{1-\beta-\gamma}e^{\gamma}\right)^{\alpha}(Q_i/S_i)^{\frac{\lambda-1}{\lambda}}S_i, \\ &= A\cdot S_i\left[(L_i/S_i)^{\beta}\cdot(K_i/S_i)^{1-\beta-\gamma}\cdot(E_i/S_i)^{\gamma}\right]^{\alpha}\cdot(Q_i/S_i)^{\frac{\lambda-1}{\lambda}}, \end{aligned} \tag{2}$$

where L_i, K_i, and E_i represent the total number of employed people, total capital stock, and total energy consumption of the city (i), respectively. Dividing both sides of **Eq. 2** by L, the total output per capita can be expressed as follows:

$$\begin{aligned} Q_i/L_i &= A^{\lambda}S_i^{1-\alpha\lambda}\left(L_i^{\beta}\cdot K_i^{1-\beta-\gamma}\cdot E_i^{\gamma}\right)^{\alpha\lambda}\cdot L_i^{-1}. \\ &= A^{\lambda}\cdot(K_i/L_i)^{(1-\beta-\gamma)\alpha\lambda}\cdot(E_i/L_i)^{\gamma\alpha\lambda}(L_i/S_i)^{\alpha\lambda-1}. \end{aligned} \tag{3}$$

It is assumed that the factor market is of the good nature of perfect competition, which means that in equilibrium, the marginal product value equal to the price of the factor holds as follows:

$$K_i = Q_i\cdot\alpha(1-\beta-\gamma)/r, E_i = Q_i\cdot\alpha\gamma/P_e, \tag{4}$$

where r and P_e represent the market price of the capital and energy, respectively. We define the following three symbols:

$$\begin{aligned} &\Phi\equiv\lambda/[1-\alpha\lambda(1-\beta)]\neq 0 \\ &\Gamma\equiv(\alpha\gamma/P_e)^{\alpha\lambda\gamma/[1-\alpha\lambda(1-\beta)]} \\ &\quad\cdot[\alpha(1-\beta-\gamma)/P_e]^{\alpha\lambda(1-\beta-\gamma)/[1-\alpha\lambda(1-\beta)]} \\ &\delta\equiv(1-\alpha\lambda)/[\alpha\lambda(1-\beta)-1]. \end{aligned}$$

According to **Equation 4**, and **Equation 3** can be rewritten as follows:

$$Q_i/L_i = \Gamma \cdot A^{\Phi} \cdot (L_i/S_i)^{\delta}. \tag{5}$$

According to the study of Ertur and Koch (2007), green TFP not only depends on the factor endowments of the city itself but is also influenced by other cities in the economic system. For example, in the potential model, Drucker and Feser (2012) discussed the spatial effect of the Marshall agglomeration economy and believed that economic agglomeration could go beyond regional boundaries and have an impact on the productivity of neighboring areas. We assume that the interdependence of green TFP between the cities works through the agglomerated spatial externalities and that the externalities generated by the agglomeration of population and economic activities in one city will break through the city boundaries and extend to other cities. However, such intercity boundary effect is affected by the frictional factors such as geographical distance and economic system difference, and the intensity of the spatial spillover of agglomeration decreases with the increase of the disturbance. According to the abovementioned analysis, green TFP (A) can be set as follows:

$$A = G_i \cdot \prod_{i \neq j}^{N} G_j^{\xi w_{ij}} \left(L_j/S_j\right)^{\zeta w_{ij}}, \tag{6}$$

where G_i is the green TFP of the city i. ξ and ζ indicate the interdependence degree of green TFP and economic agglomeration between the cities, respectively. w_{ij} is the exogenous friction term (j = 1,2,. . ., N and $j \neq i$), representing the degree of association between the city i and j. The larger the w, the greater is the connection between the cities, and $w \in (0,1)$. N is the number of cities. Substituting **Eq. 6** into **Eq. 5** and taking its logarithm further, we can get the following:

$$\begin{aligned} LnG_i = \xi \sum_{i \neq j}^{N} w_{ij} LnG_j + \zeta_1 \sum_{i \neq j}^{N} w_{ij} Ln\left(L_j/S_j\right). \\ + \left[\lambda^{-1}(\alpha\lambda - 1)\right] Ln(L_i/S_i) + \Phi^{-1} Ln(Q_i/L_i) - \Phi^{-1} Ln\Gamma. \end{aligned} \tag{7}$$

According to **Equation 7**, green TFP is not only related to the level of regional economic agglomeration but is also affected by the degree of green TFP and economic agglomeration in the surrounding areas. In addition, the impact of economic agglomeration on green TFP is characterized by periodic changes. Under different agglomeration levels, the impact direction of economic agglomeration on green TFP may be different. We will discuss this through a comparative static analysis.

Assuming that the land area is relatively fixed under the condition of Hicks neutral technology, with the increase of labor input, the factor input will deviate from the optimal allocation level of "labor-land". In addition, the marginal product of the labor input per unit of land will gradually decline. This efficiency loss caused by the additional factor input per unit of land is called the "congestion effect" of agglomeration. At the initial stage of agglomeration, that is, when $\lambda < 1/\alpha$, $\partial LnG/\partial Ln(L/S) = \lambda^{-1}(\alpha\lambda - 1) < 0$, the economic agglomeration is at a low level, and the increase of the agglomeration is not conducive to the improvement of green TFP. However, as long as λ is large enough, that is, when $\lambda > 1/\alpha$, there is $\partial LnG/\partial Ln(L/S) = \lambda^{-1}(\alpha\lambda - 1) < 0$, then the increase of the agglomeration degree will be beneficial to the improvement of green TFP. It indicates that when the degree of economic agglomeration exceeds the critical value ($1/\alpha$), the positive externalities of the agglomeration will be enough to compensate for the efficiency loss caused by the abovementioned congestion effects.

In the initial stage, driven by various factors, labor and economic activities continued to gather in the cities. The increase in the factor input per unit land area has brought about the expansion of production capacity. However, it will also lead to an increase in the energy use intensity and pollutant emissions (Ren et al., 2003). In addition, this influence is greater than the energy-saving and emission-reduction effects brought about by the agglomeration of positive externalities. For regions with a low degree of economic agglomeration, the factor prices and intensity of environmental regulations are relatively low. It may attract the inflow of some high-energy and high-polluting industries (Song et al., 2021). Although it brings about an increase in the output, it also hurts environmental quality. In addition, the benefits of this increase in the output often cannot make up for the losses from the decline in the environmental quality. Therefore, when the degree of agglomeration is low ($\lambda < 1/\alpha$), the increase in the degree of economic agglomeration has an inhibitory effect on green TFP.

Furthermore, when the degree of economic agglomeration is high enough ($\lambda > 1/\alpha$), the positive externality of the agglomeration can be significantly manifested (λ-1/λ is large). First of all, economies of the scale will effectively promote the improvement of resource utilization efficiency and centralized pollutant treatment capacity (Krugman, 1998). Second, the structure of the output will begin to shift toward low-pollution services and knowledge-intensive industries. Third, the knowledge spillover will contribute to technological progress (Balaguer & Cantavella, 2018). The application of clean technology will reduce the pollution level per unit output, and the development of pollution control technology can also reduce the environmental pollution to a certain extent. Finally, the advancement of the labor market will enhance the public demand for a high-quality environment, and thus enhance the intensity of the environmental regulation. Under the comprehensive action of these factors, for cities whose economic agglomeration level has reached a certain level, a higher agglomeration level means greater positive externalities of agglomeration economy. At this time, the improvement of the agglomeration degree will be conducive to the improvement of green TFP. Based on the abovementioned analysis, we propose the following hypotheses to be tested:

Hypothesis 1: After the other conditions remain unchanged, with the increase of economic agglomeration, green TFP shows a trend of decreasing first and then increasing after controlling the urban spatial correlation.

Hypothesis 2: Economic agglomeration has a threshold effect on the agglomeration externalities such as infrastructure sharing, knowledge spillover, advanced labor market, and the green output structure, which is the internal reason for the "U-shaped" curve relationship between economic agglomeration and green TFP.

4 METHODOLOGY AND DATA

4.1 Standard Panel Model Setting

Based on the theoretical analysis and assuming the random effect as ε_{it}, the benchmark econometric model is obtained:

$$LnGTFP_{it} = \alpha + \beta_1 LnAGG_{it} + X_{it}^{'}\beta + v_i + u_t + \varepsilon_{it}, \quad (8)$$

where *GTFP* is the green total factor productivity ("green TFP" above). *AGG* is the degree of economic agglomeration. X' is the control variable matrix. Subscripts i and t represent the city and year, respectively. α is the constant term, and β is the coefficient vector of the variable. Considering that the research sample is 281 prefecture-level cities, which is close to the total sample, the fixed-effect model is used. v_i is the fixed effect of the city, and u_t is the fixed effect of the year.

4.2 Construction of a Spatial Econometric Model

4.2.1 The Setting of a Spatial Econometric Model

Based on the abovementioned analysis, we further consider the spatial spillover effect of *GTFP* and *AGG*. We reflect it in the spatial lag term in the form of a spatial weight matrix to make the estimation result more realistic. Based on **Eq. 7** and LR test[1], the SDM model is used:

$$\begin{aligned} LnGTFP_{it} = \alpha + \delta WLnGTFP_{it} + \beta_1 LnAGG_{it} + \beta_2 WLnAGG_{it}, \\ + X_{it}^{'}\beta_3 + WX_{it}^{'}\beta_4 + v_i + u_t + \varepsilon_{it}, \end{aligned} \quad (9)$$

where W is a 281 × 281 spatial weight matrix. $WLnGTFP_{it}$, $WLnAGG_{it}$, and WX_{it} are the spatial lagged items of a dependent variable, main explanatory variable, and control variable, respectively, reflecting the influence of spatial relations on *GTFP*. δ is the spatial autoregressive coefficient, which reflects the influence of *GTFP* in this region in the surrounding areas, and its value range is (−1, 1). Considering that the spatial lag term is related to the random disturbance term, we refer to the practice of Elhorst (2014) and use the dynamic SDM model. The final model is set as follows:

$$\begin{aligned} LnGTFP_{it} = \alpha + \tau LnGTFP_{it-1} + \delta WLnGTFP_{it} + \eta WLnGTFP_{it-1}, \\ + \beta_1 LnAGG_{it} + \beta_2 WLnAGG_{it} + X_{it}^{'}\beta_3 + WX_{it}^{'}\beta_4 + v_i + u_t + \varepsilon_{it}, \end{aligned} \quad (10)$$

where $LnGTFP_{it-1}$ is the first-order time lag of the *GTFP*. $WLnGTFP_{it-1}$ is the first-order time and space lag of the *GTFP*. τ is the regression coefficient of the lag period, reflecting the influence of the *GTFP* in the previous period on the current period. η is the coefficient of the time-space lag term, representing the influence of the *GTFP* in the local period in the neighboring area in the current period. It should be noted that due to the disturbance of the spatial correlation of variables, the change of the explanatory variable in region i will affect itself by affecting the other regions, but this "feedback effect" cannot be captured by the traditional point estimation methods (Chen and Lee, 2020). Therefore, it is necessary to use a dynamic SDM model to conduct the effect decomposition of the estimated coefficients (Elhorst, 2010) to separate the direct impact and spatial spillover effect.

4.2.2 The Setting of a Spatial Weight Matrix

The geographical distance matrix, economical distance matrix, and nested matrix of both are used for the spatial econometric analysis. The geographical distance matrix is set as follows:

$$W_{dij} = \begin{cases} 1/d_{ij}, i \neq j \\ 0, i = j \end{cases}, \quad (11)$$

where d_{ij} is the distance between city i and j, which is calculated by the longitude and latitude coordinates of the city. The economic distance weight matrix is set as follows:

$$W_{eij} = \begin{cases} 1/\left|\bar{Y}_i - \bar{Y}_j\right|, i \neq j \\ 0, i = j \end{cases}, \quad (12)$$

where $\bar{Y}_i$ represents the average per capita GDP of the city i during the sample period (2003–2018). In addition, considering that the spatial correlation effect between the cities is likely to be the result of the joint action of geographical proximity and economic correlation, an asymmetric spatial weight matrix W_{mix}, which takes the geographical distance and economic attributes into account, is constructed concerning the existing studies (Yuan et al., 2020):

$$\begin{aligned} W_{mix} = W_d \times diag\left(\bar{Y}_1/\bar{Y}, \bar{Y}_2/\bar{Y}, ..., \bar{Y}_n/\bar{Y}\right), \\ \bar{Y}_i = \sum_{t_0}^{t_1} Y_{it}/(t_1 - t_0 + 1), \bar{Y} = \sum_{t_0}^{t_1} Y_t/(t_1 - t_0 + 1), \end{aligned} \quad (13)$$

where $\bar{Y}_i$ is the per capita GDP of the city i during t_0~t_1, $\bar{Y}$ is the average per capita GDP of each city during the sample period and W_d is the spatial weight matrix of the geographic distance.

4.3 Variable construction

4.3.1 Green Total Factor Productivity

Referring to the research of Li and Xu (2018), Lin and Tan (2019), a single city was set as a basic decision unit, and the nonradial directional distance function (NDDF) was used to construct the evaluation index of the green total factor productivity. The input factors include labor (L), capital (K), and energy (E). The output factors include the expected output (*GDP*) and unexpected output [sulfur dioxide (S), wastewater (W), and soot (D)]. In the NDDF, the weights of each input–output variable have good flexibility (Lin and Du, 2015). The weights of L, K, E, *GDP*, S, W, and D are, respectively, set as 0, 0, 1/3, 1/3, 1/9, and 1/9, that is, the weight vector is $w = (0, 0, 1/3, 1/3, 1/9, 1/9, 1/9)^T$. The reasons are as follows: First, when there is no prior information, it is more reasonable to treat all the input and output factors equally

[1]The LR test result is shown in **Table 3**.

in the construction of the total factor productivity index (Lin and Liu, 2015). Therefore, the factor input, expected output, and nonexpected output are each given a weight of 1/3. Second, to understand the real situation of the energy input inefficiency, the inefficiency of capital and labor should be broken down (Li and Xu, 2018). Therefore, the weight of the labor and capital is set to 0, and the weight of the energy input is 1/3. Third, according to the weight vector, the direction vector can be further defined as $g = (0, 0, -E, GDP, -S, -W, -D)^T$. At this point, the linear optimal solution of the distance function can be performed, and the optimal solution can be recorded as $\beta^* \equiv (\beta_E^*, \beta_{GDP}^*, \beta_S^*, \beta_W^*, \beta_D^*)^T$. Based on the optimal solution, the *GTFP* evaluation index can be constructed[2]:

$$GTFP_{it} = \frac{1}{2}\left[\frac{\left(E_{it} - \beta^*_{E,it}\cdot E_{it}\right)/\left(GDP_{it} + \beta^*_{G,it}\cdot GDP_{it}\right)}{E_{it}/GDP_{it}}\right]$$

$$+\frac{1}{2}\left[\frac{1}{3}\sum_{j=S,W,D}\frac{\left(j_{it} - \beta^*_{j,it}\cdot j_{it}\right)/\left(GDP_{it} + \beta^*_{GDP,it}\cdot GDP_{it}\right)}{j_{it}/GDP_{it}}\right]$$

$$= \frac{1 - \beta^*_{E,it} + \frac{1}{3}\left(1 - \beta^*_{S,it}\right) + \frac{1}{3}\left(1 - \beta^*_{W,it}\right) + \frac{1}{3}\left(1 - \beta^*_{D,it}\right)}{2\left(1 + \beta^*_{GPD,it}\right)},$$

4.3.2 Economic Agglomeration

Based on the theoretical analysis, we use the urban employment density (labor force per unit land area) to measure the degree of economic agglomeration and then use the output density (the sum of the added value of the secondary and tertiary industries per unit land area) as a surrogate index for the robustness test. In addition, the quadratic term of the economic agglomeration variable is introduced to test Hypothesis 1.

4.3.3 Selection of Control Variables and Tool Variables

4.3.3.1 Selection of Control Variables

1) The GDP is measured by the natural logarithm of per capita GDP. According to EKC's argument, with economic development, environmental pollution generally experiences a process of rising first and then falling (Stern, 2004). To take into account this inverted "U-shaped" curve relationship, the quadratic term of the logarithm of per capita GDP is also added.
2) The industrial structure (IS) is measured by the proportion of the added value of the secondary industry in GDP. The studies have shown that most of the energy consumption and environmental waste come from the secondary industry, which has become the main source of urban environmental pollution (Cheng et al., 2018).
3) Foreign direct investment (FDI) is measured by the natural logarithm of the actual foreign investment. On one hand, some "tree high" industries often flow into a region in the form of FDI, thus making the region a "pollution haven"; but on the other hand, the inflow of FDI may also provide the local advanced technology and equipment to optimize the production process.
4) The energy consumption structure (ECS) is measured by the ratio of industrial power consumption to urban total power consumption. Excessive reliance on fossil fuels in the energy consumption structure will bring adverse effects on China's economic transformation and environmental governance (Li Z. et al., 2019).
5) The intensity of government intervention (GI) is measured by the proportion of local fiscal expenditure in GDP. In the background of the continuous strengthening of the environmental protection assessment, environmental performance becomes an important indicator affecting the promotion of officials. Such incentives lead to government intervention in the allocation of resources in the market, which has an impact on the economic growth and environmental quality.
6) The environmental regulation (ER) is measured by the removal rate of industrial sulfur dioxide. The ER means that the government departments formulate relevant laws and regulations to limit and control waste emissions from industrial enterprises (Ren et al., 2018). Reasonable ER is conducive to promoting the production units to achieve energy conservation and emission reduction (Cai et al., 2016).
7) The infrastructure is measured by per capita road area. The infrastructure sharing can affect the economic growth and environmental quality by reducing the transportation costs and facilitating information exchange (Banerjee et al., 2020; Wang et al., 2020), so it is necessary to consider its impact on the *GTFP*.
8) The technological effort (TE) is measured by the patents per 10,000 people. The TE plays a vital role in the environmental protection by reducing the energy consumption and pollutant emission per unit output (Ying et al., 2021).

4.3.3.2 Selection of Utility Variables

In the setting of the spatial econometric model, the explanatory variable is assumed to be exogenous. However, *AGG* is not an exogenous variable. *AGG* will affect the *GTFP*, and at the same time, the areas with high *GTFP* tend to have a higher *AGG* degree. There is a reverse causal relationship between *GTFP* and *AGG*. To overcome this endogeneity problem, we use "topographic relief" (*Iv1*) and "whether there was a train in 1933" (*Iv2*) as the instrumental variables of *AGG*. *Iv1* can be used as an instrumental variable of *AGG* because the topographic relief is related to population distribution and population density (Feng et al., 2007) At the same time, as a geographically naturally formed objective factor, it has nothing to do with the disturbance term of **Eq. 10**. *Iv2* can become an instrumental variable of *AGG* in that railway is conducive to the formation of cities and agglomeration. It is related to the degree of *AGG*. Meanwhile, as a historical fact, since 1933 is far from the beginning period of the sample, it can be considered independent of the perturbation term of **Eq. 10**. Logically, the two abovementioned instrumental variables satisfy the prerequisites of "correlation" and "echogenicity".

[2]The complete process is shown in **Supplementary Appendix S1**.

TABLE 1 | Descriptive statistics of the variables.

Variables	N	Mean	Std.Dev	Min	Max
GTFP	4,496	0.881	0.387	0.481	14.179
Ln*AGG*	4,496	3.373	1.137	−0.743	8.338
Ln*AGG_SQ*	4,496	12.668	8.218	0.066	69.522
Ln*GDP*	4,496	10.184	0.850	4.636	15.680
Ln*GDP_SQ*	4,496	104.434	17.218	21.496	245.867
IS	4,496	0.482	0.110	0.027	0.910
Ln*FDI*	4,496	3.112	1.752	0	9.604
ECS	4,496	0.658	0.178	0.023	1
GI	4,496	0.206	0.187	0.031	6.041
ER	4,496	0.781	0.231	0.002	1
Infrastructure	4,496	5.405	4.042	0.083	53.042
TE	4,496	0.006	0.003	0	0.095

*Note: Ln*AGG_SQ*, is the square term of Ln*AGG*. *GDP_Sq *is the square term of* GDP.

We use ArcGIS and China's 1:1,000,000 Digital Elevation Model data to calculate *Iv1* (RDLS). Within each unit, the RDLS calculation formula is as follows:

$$RDLS = \{Max(H) - Min(H) \cdot [1 - A^{-1} \cdot P(A)]\}/500,$$

where $Max(H)$ and $Min(H)$ represent the highest and lowest elevations (m) of the city, respectively. A is the total area of the city (km^2), and the 10 km × 10 km grid is selected as the basic evaluation unit. $P(A)$ is the flat area of the city, and the judgment standard is that the maximum height difference within 25 km^2 is less than or equal to 30 m (Chen, 1993).

Definition of the *Iv2*: if the train passed through the city *i* in 1933, the variable is 1; otherwise, it is 0. *Iv2* can be judged by combining the history of the railway construction in "China's Transport History" and the full map of China's railways in "Fact Sheet of China Railways".

4.3.4 Sample Selection and Data

The data are obtained mainly from the "Statistical Yearbook of Chinese Cities" and CEIC database. To ensure the comparability of the data, the indexes related to the market value are deflated with 2003 as the base period. The perpetual inventory method is used to convert the fixed asset investment into the fixed asset stock[3]. The data of each index are obtained from the official website of the National Bureau of Statistics of China. Since the GDP deflators of the prefecture-level cities were not fully disclosed, the GDP deflators of the provinces under the prefecture-level cities were used to supplement the missing years. The interpolation method is used to solve the problem of the outliers or missing values, and the sample of the cities with the seriously missing data is eliminated. The panel data set of 281 cities at the prefecture-level and above in China from 2003 to 2018 is adopted. The spatial weight matrix in the geographical relations between the various regions comes from China's geographic information system website providing 1:1,000,000 electronic map[4]. Descriptive statistics of each variable are shown in **Table 1**.

5 RESULTS AND DISCUSSIONS

5.1 The Spatiotemporal Trend of Agglomeration and Green Total-Factor Productivity

5.1.1 Time-Variation

According to the trend of AGG and GTFP during the sample period (**Figure 1**), it can be seen that both of these show obvious characteristics of phased changes. The sample period is divided into two stages for further analysis. The first stage (2003–2009) is a period known as the "old normal" of China's economy. At this stage, along with the growth of economic agglomeration, the fluctuation of the GTFP declined. This is closely related to the influx of the foreign capital caused by China's accession to the WTO in 2001 (Li M. et al., 2019). The second stage (2010–2018) is a period known as the "new normal" of China's economy. At this stage, the *AGG* has a steady and declining growth trend, and the *GTFP* is in the stage of fluctuation, which may be related to the global financial crisis in 2008 and the transformation of China's extensive development mode (Ying et al., 2021). Intuitively, *AGG* has obvious cyclical characteristics on the *GTFP*, which provides a preliminary basis for us to explore the nonlinear "U-shaped" impact of *AGG* on the *GTFP*.

5.1.2 Spatial-Variation

We analyzed the spatial change characteristics of *AGG* and GTFP. By drawing the development trend of the *AGG* and GTFP during the "11th 5-Year Plan" (2006–2010) and "12th 5-Year Plan" (2011–2015) period. The reason for choosing these two time periods is that the Chinese government formulates new economic developmental strategies and policies every 5 years. In the five-year plan, the economic development strategy is relatively stable, and the observation results are more comparable.

During the "11th" period, China has set significant reduction in the total discharge of the major pollutants as a binding indicator for economic and social development. However, the overall deterioration of the environmental conditions has not yet been fundamentally curbed. It was not until the "12th" period that the effective breakthroughs were made in sustainable development. As shown in **Figure 2**, during the "11th" period, *AGG* was relatively concentrated in the core major cities. However, during the "12th" period, the *AGG* activities gradually spread from the eastern coastal areas to the internal areas. Shift from being concentrated in the core large cities to being concentrated in the regional central city clusters, especially in the Yangtze River Delta, Pearl River Delta, and Chengdu-Chongqing double-city economic circles. Similarly, the high-level GTFPs are mainly concentrated in the eastern coastal areas

[3]The formula is: $K^s_{it} = K^f_{it} + (1-\delta)K^s_{i,t-1}, K^s_{i0} = K^f_{i0}/(g+\delta)$, where K_{its} and K_{itf} represent the capital stock and fixed asset investment of the city *i* in the *t* year. Subplot 0 is the initial year. δ is the depreciation rate, taking 8.5%. *g* is the average annual growth rate of the fixed asset investment of the selected sample cities.

[4]The website of the Geographic Information Resources Directory Service System is: https://www.webmap.cn/main.do?method=index.

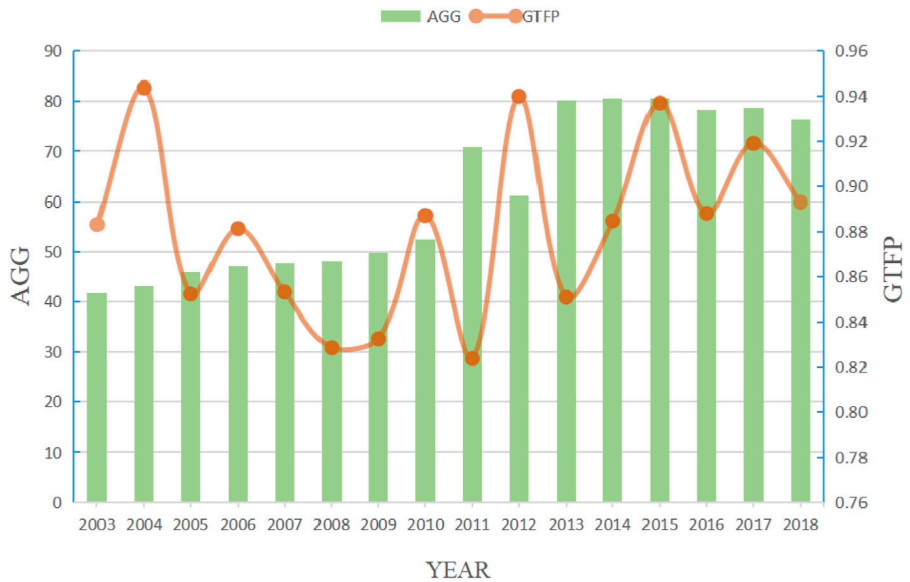

FIGURE 1 | Temporal variation of the *GTFP* and *AGG*.

during the "11th" period. During the "12th" period, it rapidly shifted to the central and western inland areas. This trend of change is a manifestation of the transformation of China's green economy development. *AGG* has promoted the transformation of economic development and has an impact on the GTFP. However, from the perspective of the matching degree between the geographical distribution of labor and the layout of the GTFP, the change of the former is relatively lagging.

5.2 The Results of Spatial Econometric Estimation

The abovementioned analysis shows that there is a possible spatial correlation between the *AGG* and *GTFP*. In addition, the test results of the global Moran index prove that such spatial correlation should be taken into account in the setting of the econometric model. The value of the global Moran's I is between −1 and 1. Positive values indicate that the variables are positively correlated in space. **Table 2** shows that there is a spatial correlation between the *GTFP* and *AGG*. So, it is the right choice to use the spatial econometric model that considers spatial correlation between the variables. Therefore, we adopt a spatial econometric model to estimate the parameters.

However, it is necessary to investigate whether the dynamic SDM model is suitable. According to the test results (**Table 3**), the spatial autocorrelation test of the OLS regression residuals shows that it is reasonable to construct a spatial measurement model. The LR test shows that the estimation results of the dynamic SDM model are robust. The Hausman test indicates that we should use the fixed-effect model.

The dynamic SDM model with the spatiotemporal fixed effects was finally used, and the parameter estimation was conducted according to the error correction MLE method provided by Lee & Yu (2010). In addition, to test the necessity of introducing a dynamic model, **Table 4** also lists the regression results of the static spatial Dubin model under the dual fixed effect[5]. But, we mainly analyze the results of the spatiotemporal fixed effect of the dynamic SDM.

The estimated results are shown in **Table 4**. From the time dimension, the parameter estimates of the *GTFP* lagging one period are all significantly positive. The reason may be that some economic policy adjustments have a time lag (Guo et al., 2021). From the perspective of spatial dimension, there is a positive spatial correlation effect. Driven by the natural flow of the atmosphere and trade between neighboring regions, the development of the *GTFP* in this region is closely related to the surrounding regions. From the perspective of both time and space, the parameter estimation of the spatial lag term of the last period of *GTFP* is significantly negative. The possible reason is that the development of a green economy in this region has a "warning effect" on the neighboring regions.

Compared with the static SDM, the dynamic SDM has stronger explanatory power to the econometric models. In addition, according to the logarithmic likelihood value and goodness of fit in **Table 4**, the estimated values in the case of geographic and economic distance nested matrix are better than those in the nested matrix. Therefore, we will focus on the estimation results of the nested matrix of the dynamic SDM. It should be noted that the spatial spillover effect measured by the dynamic SDM is a global effect rather than a local effect. In this case, the point estimation results of the dynamic SDM model itself are only valid on the direction of action and significance level but do not represent the marginal impact of the explanatory variables. To investigate the influence of the explanatory variables

[5]Compared with the static SDM model which only contains the *GTFP*, the dynamic SDM model also has both the time lag effect and space-time double lag effect.

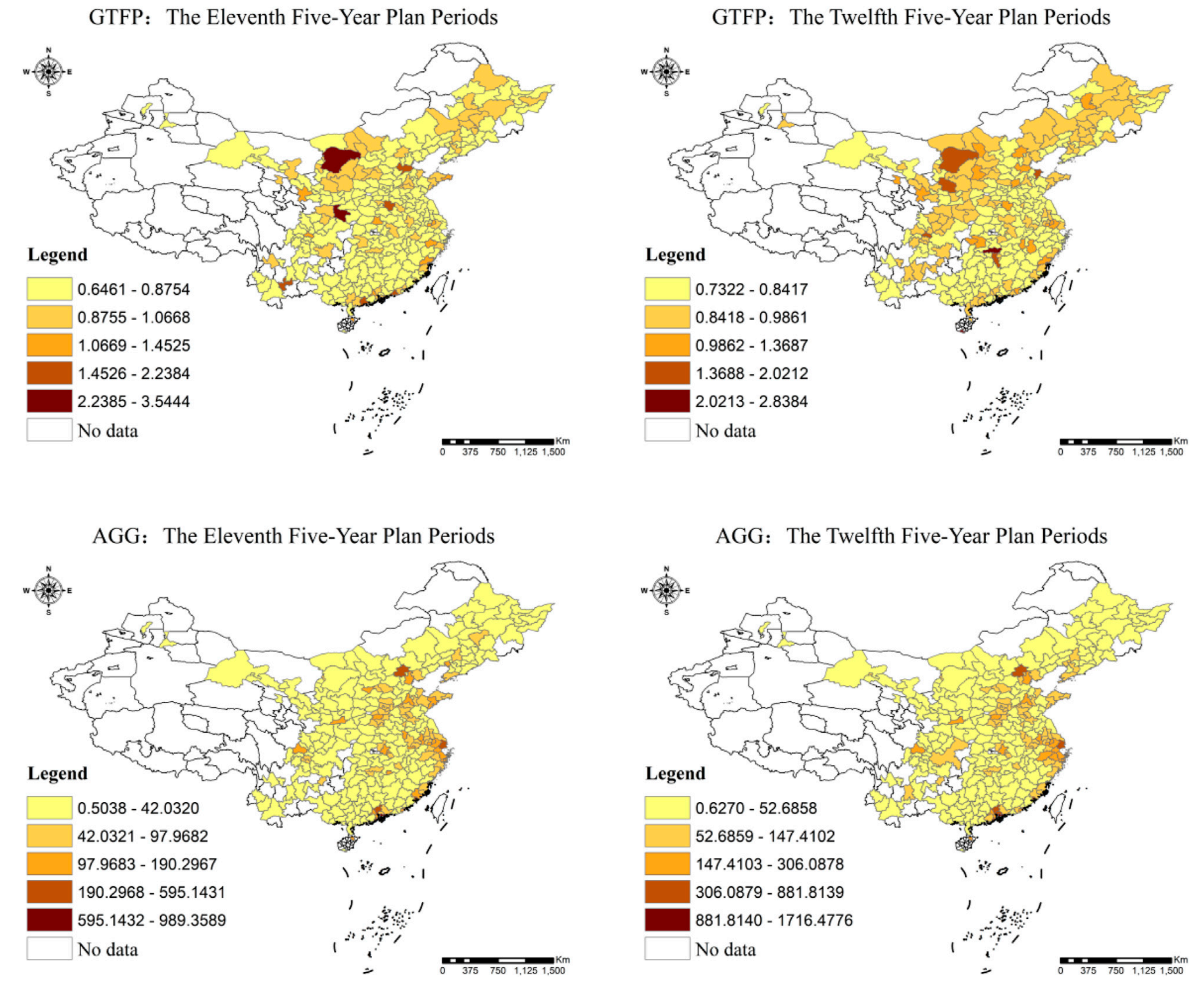

FIGURE 2 | Spatial variation of the *GTFP* and *AGG*.

TABLE 2 | Spatial autocorrelation test.

Year	GTFP	LnAGG	LnAGG_SQ
2003	0.019*** (3.875)	0.096*** (16.193)	0.096*** (16.202)
2004	0.149*** (5.732)	0.101*** (17.045)	0.102*** (17.146)
2005	0.143*** (5.624)	0.105*** (17.705)	0.107*** (17.969)
2006	0.029* (1.830)	0.108*** (18.204)	0.111*** (18.765)
2007	0.004* (1.659)	0.112*** (18.852)	0.117*** (19.681)
2008	0.056** (2.229)	0.115*** (19.286)	0.120*** (20.202)
2009	0.051** (1.988)	0.116*** (19.403)	0.122*** (20.461)
2010	0.039*** (3.826)	0.119*** (20.018)	0.126*** (21.155)
2011	0.063*** (3.471)	0.114*** (19.164)	0.107*** (18.181)
2012	0.019*** (2.632)	0.119*** (19.976)	0.124*** (20.780)
2013	0.017*** (4.323)	0.129*** (21.574)	0.146*** (24.357)
2014	0.034** (2.204)	0.134*** (22.449)	0.152*** (25.450)
2015	0.046*** (2.769)	0.133*** (22.250)	0.149*** (24.915)
2016	0.008** (1.972)	0.137*** (22.879)	0.154*** (25.662)
2017	0.012*** (2.616)	0.136*** (22.733)	0.151*** (25.190)
2018	0.044*** (2.757)	0.140*** (23.392)	0.156*** (26.002)

Note: *p < 0.1, **p < 0.05, ***p < 0.01.

on the explained variables, the direct and indirect effects of the explanatory variables should be further calculated based on the point estimation results (Elhorst, 2014)[6]. The direct and indirect effects can be divided into short-term effects and long-term effects from the perspective of a time dimension, respectively, reflecting the short-term impact and the long-term impact. **Table 5** reports the estimation results.

From the effect decomposition results in **Table 5**, the absolute value of the influence coefficient of most long-term effects is greater than that of the short-term effects. It shows that *AGG* has a more obvious long-term impact on the *GTFP*. In addition, there is an obvious "U-shaped" curve relationship between *AGG* and

[6]The direct effect refers to the impact of economic agglomeration on the green TFP in the region, which includes the feedback effect. However, due to its small value, generally, it can be ignored; indirect effect refers to the influence of the change of a local factor on the green TFP in the neighboring area, namely, the spatial spillover effect of an influencing factor.

TABLE 3 | Model selection checklist.

Test	Wd1	Wd2	We	Wmix1	Wmix2
LM-lag	38.841***	15.227***	13.452***	39.287	12.559***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Robust LM-lag	5.510***	5.805***	0.038	11.216	4.569***
	(0.019)	(0.016)	(0.844)	(0.001)	(0.033)
LM-error	69.410***	21.725***	13.822***	61.656	17.474***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Robust LM-error	36.080***	12.304***	0.408	33.585	9.485***
	(0.000)	(0.000)	(0.523)	(0.000)	(0.002)
LR-lag	74.79***	58.33***	14.53**	73.58***	57.04***
	(0.000)	(0.000)	(0.0410)	(0.000)	(0.000)
LR-error	73.35***	58.62***	15.51**	71.49***	56.34***
	(0.000)	(0.000)	(0.0344)	(0.000)	(0.000)
Hausman	224.53***	19.13*	616.04***	120.50***	430.44***
	(0.000)	(0.085)	(0.000)	(0.000)	(0.000)

Note: Wd1 is the first-order geographical distance weight matrix; Wd2 is the second-order geographical distance weight matrix; We represent the weight matrix of the economical distance; Wmix1 is the first-order geographical and economical distance nested weight matrix; Wmix2 is a second-order geographical and economical distance nested weight matrix. The same applies to the following tables.Note: *p < *0.1,* **p < *0.05,* ***p < *0.01.*

TABLE 4 | Spatial econometric estimation results under different spatial matrices.

Variables	Wd		We		Wmix	
	Static SDM	Dynamic SDM	Static SDM	Dynamic SDM	Static SDM	Dynamic SDM
Ln*AGG*	−0.087** (−2.33)	−0.100*** (−2.77)	−0.070** (−2.02)	−0.086** (−2.54)	−0.081** (−2.23)	−0.100*** (−2.81)
Ln*AGG_SQ*	0.006 (1.45)	0.009** (2.18)	0.002 (0.55)	0.007* (1.81)	0.005 (1.25)	0.008** (2.15)
GTFP(-1)	—	0.505*** (35.03)	—	0.512*** (35.65)	—	0.503*** (34.80)
W×Ln*GTFP*	0.537*** (3.09)	0.433** (2.53)	0.007 (0.20)	0.071** (2.29)	0.347** (2.40)	0.287* (1.96)
W×Ln*GTFP*(-1)	—	−0.544** (−2.01)	—	0.080* (1.76)	—	−0.651*** (−3.05)
W×Ln*AGG*	−0.337 (−0.82)	−0.209 (−0.52)	0.041 (0.42)	0.098 (1.06)	−0.469 (−1.44)	−0.247 (−0.76)
W×Ln*AGG_SQ*	−0.018 (−0.41)	−0.020 (−0.48)	−0.008 (−0.82)	−0.014 (−1.40)	0.015 (0.51)	−0.003 (−0.12)
X′	Yes	Yes	Yes	Yes	Yes	Yes
X′W	Yes	Yes	Yes	Yes	Yes	Yes
City	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Obs	4,496	4,496	4,496	4,496	4,496	4,496
Log L	1,647.3093	2,214.0262	1,651.0093	2,116.8443	1,658.6039	2,126.2756
R^2	0.014	0.253	0.010	0.298	0.021	0.273

Note: *p < *0.1,* **p < *0.05,* ***p < *0.01. T-test value in parentheses. Log L is the log-likelihood.* R^2 *is the adjusted-*R^2*. Wd is the first-order geographical distance weight matrix. We is the weight matrix of the economic distance. Wmix is the first-order geographic and economic distance nested weight matrix. GTFP(-1) is the lagging of GTFP.*

TABLE 5 | The estimation result of the effect decomposition.

Weight matrices	Types of effects	Ln*AGG*	Ln*AGG_SQ*
Wd	Short-term direct effect	−0.096*** (−2.75)	0.008** (2.23)
	Short-term spillover effect	−0.096 (−0.31)	−0.019 (−0.62)
	Long-term direct effect	−0.196*** (−2.66)	0.017** (2.21)
	Long-term spillover effect	−0.008 (−0.03)	−0.028 (−0.86)
We	Short-term direct effect	−0.082** (−2.55)	0.006* (1.84)
	Short-term spillover effect	−0.109 (−1.12)	−0.015 (−1.49)
	Long-term direct effect	-0.165** (-2.47)	0.012* (1.74)
	Long-term spillover effect	−0.231 (−0.96)	−0.034 (−1.37)
Wmix	Short-term direct effect	−0.096*** (−2.81)	0.008** (2.20)
	Short-term spillover effect	−0.152 (−0.55)	−0.006 (−0.27)
	Long-term direct effect	−0.193*** (−2.71)	0.016** (2.18)
	Long-term spillover effect	−0.029 (−0.11)	−0.015 (−0.65)

Note: *p < *0.1,* **p < *0.05,* ***p < *0.01. T-test value in parentheses.*

GTFP, which is verified by Hypothesis 1. The possible reason is that when the degree of *AGG* is low, there is a mismatch between the needs of the infrastructure construction and the increasing influx of labor. Economic activities are mainly manifested in the redundant construction, blind investment, and energy waste (Wang and Wang, 2019). This will cause a pressure on the local economy and the carrying capacity of the natural resources. This is similar to the research conclusion of Bashir et al. (2021). At this stage, *AGG* is not conducive to the promotion of *GTFP*.

However, as *AGG* continues to increase, the positive externalities brought about by agglomeration gradually appears, such as the reduction of transportation costs (Pierre et al., 2012), more employment opportunities, and increased productivity (Ines, 2020). Specifically, agglomeration can promote spatial distribution and combination optimization of labor, capital, energy, and environmental factors, and labor and capital factors have a certain substitution effect on the environmental factors, which will reduce the energy consumption and the burden on the environment (Sharma et al., 2021). Compared with a low degree of agglomeration, cities with a high degree of agglomeration can share the pollution control infrastructure. It contributes to saving pollution control costs and reducing pollution emissions. The indirect effect of *AGG* on *GTFP* is negative in the short and long term, but not significant. An insufficient level of the regional linkage may be the reason that hinders *AGG* from exerting spatial spillover effects.

5.3 Influence Mechanism Inspection

According to the theoretical analysis, *AGG* may influence the *GTFP* through sharing effect, structure effect, and knowledge spillover effect. To test it, we consider the following four specific factors: 1) Infrastructure sharing is measured by the urban per capita road area. 2) The green output structure is measured by the ratio of the output value of the tertiary industry to that of the secondary industry. 3) Knowledge spillover is measured by the ratio of the number of teachers in urban colleges and universities to the total labor force. 4) The level of the labor market is measured by the ratio of the number of students in urban colleges and universities to the total labor force. Furthermore, based on the classical mediating effect-test model (Chen and Lee, 2020), the following model was established for parameter estimation:

$$Z_{it} = \alpha + \varphi Z_{it-1} + \lambda W Z_{it} + \theta W Z_{it-1} + \rho_1 LnAGG_{it} + \rho_2 W LnAGG_{it} + X_i^{'}\rho_3 + W X_i^{'}\rho_4 + v_i + u_t + \varepsilon_{it}, \tag{14}$$

where Z_{it} is the possible path. Other parameter settings are consistent with the model **Eq. 10**, and the control variables added in the regression are the same as that in **Eq. 10**. In the specific verification process, the existing control variables can be changed into mediating variables[7].

The regression results are shown in **Table 6**. The direct effect estimation results show that the AGG has a U-shaped impact on infrastructure sharing, labor market advancement, and knowledge spillover. But the impact of AGG on the output structure is in an inverted "U" shape. This means that the "U-shaped" impact of *AGG* on the *GTFP* is realized through agglomeration externalities such as infrastructure sharing, labor market upgrading, and knowledge spillover. At the initial stage of agglomeration, the output structure plays a positive role, while the effect of the other three agglomeration externalities is not obvious and there are some negative effects. However, when the degree of *AGG* exceeds the threshold value, the positive externalities of the agglomeration begin to appear, and the improvement of the degree of agglomeration is conducive to the improvement of the *GTFP*.

[7]For example, when the transmission path is "infrastructure", the variable from the control variable is removed and used as an intermediate variable.

5.4 Robustness Test

5.4.1 Replace the Core Explanatory Variables

The selection of the indicators is crucial to the research conclusion. It is a common practice to take employment density as the indicator to measure the degree of *AGG*. However, when the research sample is Chinese cities, this indicator may have some defects: According to China's urban land-use standards, residents in the big cities are allowed to enjoy more per capita land-use area than those in small cities, which may have some influence on the measurement of *AGG* degree. Drawing on the practice of existing research (Shao et al., 2019), the ratio of the sum of the added value of the secondary and tertiary industries to the area is used as a new explanatory variable.

5.4.2 Replace the Spatial Weight Matrix and Remove Some Samples

In the spatial econometric model, the different weight matrices have a great influence on the estimation results. According to the geographical distance weight matrix set above, the second-order geographical distance weight matrix is further constructed, and the nested matrix of the second-order geographical distance and economic distance is considered. In addition, to avoid some unobserved and time-varying influences caused by the special administrative status of "municipalities directly under the central government", four municipalities (Beijing, Chongqing, Shanghai, and Tianjin) are excluded.

5.4.3 Alleviate Endogeneity Problems

According to the loose assumptions of the GMM model of the dynamic panel systems, the lagged terms of the explained variables and endogenous variables can be used as instrumental variables to solve the partial endogeneity problems. Specifically, the lagged variables of the *AGG* and its spatial lagged items, as well as the lagged variables of *GTFP* and *GTFP* spatial lagged items, were used as instrumental variables. In addition, considering that the abovementioned methods cannot solve the inverse causal relationship between *AGG* and *GTFP*, we further use the above-constructed variables of *Iv1* and *Iv2*.

The estimated results (**Supplementary Appendix SC**) show that the main results do not substantially change after changing the variable index, changing the spatial weight matrix, removing part of the samples, and alleviating the endogeneity problem.

TABLE 6 | The results of the mediating effect test.

Variables	Types of effects	(1) Infrastructure	(2) Upgrading of the labor market	(3) High-level industrial structure	(4) Knowledge spillover
Ln*AGG*	Short-term direct effect	0.198*** (3.54)	−0.286*** (−5.43)	0.105*** (3.84)	−0.233*** (−4.38)
	Short-term indirect effect	0.515 (1.34)	1.461*** (3.18)	1.026*** (3.21)	−0.631 (−1.28)
	Long-term direct effect	0.451*** (6.87)	−0.427*** (−5.45)	0.131*** (3.81)	−0.327*** (−4.31)
	Long-term indirect effect	0.833 (1.52)	1.867*** (3.21)	1.156*** (3.04)	−0.520 (−1.06)
Ln*AGG_SQ*	Short-term direct effect	0.008** (2.20)	0.012** (2.16)	−0.011*** (−3.62)	0.003 (0.46)
	Short-term indirect effect	−0.077* (−1.71)	−0.097** (−2.47)	−0.078*** (−2.90)	0.128*** (2.78)
	Long-term direct effect	0.016** (2.18)	0.018** (2.18)	−0.014*** (−3.60)	0.002 (0.40)
	Long-term indirect effect	−0.088* (−1.78)	−0.122** (-2.47)	−0.088*** (−2.75)	0.091*** (2.87)
X′	—	Yes	Yes	Yes	Yes
X′W	—	Yes	Yes	Yes	Yes

*Note: *p < 0.1, **p < 0.05, ***p < 0.01. T-test value in parentheses. The control variables include X′ and X′W.*

TABLE 7 | The estimated results of the agglomeration by industry.

Variables	AGG2				AGG3			
	Short-term		Long-term		Short-term		Long-term	
	Direct	Spillover	Direct	Spillover	Direct	Spillover	Direct	Spillover
Ln*AGG2*	−0.044*** (−2.94)	−0.111 (−0.76)	−0.087*** (−2.81)	−0.052 (−0.37)	—	—	—	—
Ln*AGG2*_SQ	0.002 (1.01)	−0.003 (−0.22)	0.005 (1.01)	−0.005 (−0.39)	—	—	—	—
Ln*AGG3*	—	—	—	—	−0.084** (−2.25)	−0.182 (−0.63)	−0.168** (−2.17)	−0.078 (−0.27)
Ln*AGG3*_SQ	—	—	—	—	0.011** (2.23)	−0.014 (−0.46)	0.022** (2.22)	−0.026 (−0.81)

*Note: *p < 0.1, **p < 0.05, ***p < 0.01. T-test value in parentheses. The results are estimated based on the nested matrix.*

5.5 Further Discussion

5.5.1 Industry Heterogeneity Test

Next, we distinguish between the secondary industry and the tertiary industry agglomeration. The number of workers in the secondary industry per unit of the land area is used to measure secondary industry agglomeration (*AGG2*). The number of people working in the tertiary industry per unit land area is used to measure tertiary industry agglomeration (*AGG3*). The estimated results are shown in **Table 7**.

The relationship between the *AGG*2 and GTFP also presents a U-shaped curve. In the initial stage of agglomeration, although the rapid concentration of the economic activities has brought about the growth of economic output, the agglomeration that focuses on heavy industries has also increased energy consumption and pollutant emissions (Lan et al., 2021). In addition, when the economic production activities are mainly homogenized and low-level repeated construction, it will be difficult to produce the obvious economies of scale, knowledge spillover, and synergy effects (Wang & Wang, 2019). This is consistent with the research conclusions of Shahzad et al. (2021) and Xia et al. (2022). However, when the *AGG*2 has developed to a certain level, its capital-intensive characteristics will bring opportunities for development. The concentration of manpower and material resources is conducive to reducing the emission reduction costs (Yuan et al., 2020). At this stage, the agglomeration effect is enough to make up for the negative impact caused by the energy use and pollution, so it has a promoting effect on the GTFP. As far as the tertiary industry is concerned, it is mostly "green" industries such as the service industry and tourism, which use relatively little energy in the production process and emit relatively few pollutants. Similarly, there is a "U-shaped" curve relationship between the *AGG*3 and GTFP. However, no matter the *AGG*2 or the *AGG*3, its influence effect is limited to the local area. This is similar to the conclusion of Shahzad et al. (2022). The possible reason is that the agglomeration of the secondary and tertiary industries is of low quality, which leads to spatial mismatch between the industrial structure of the region and the surrounding areas, the disconnection between the developmental demands of the regions.

5.5.2 Regional Heterogeneity Test

China's various regions have obvious characteristics of heterogeneity in the economic structure[8]. The division of east, middle, and west reflects the differences in the level of economic development and labor distribution among the regions. Therefore, we further divide the regional samples for parameter estimation. The results obtained are shown in **Table 8**.

[8]Three areas are, respectively, the most populated in the developed economic times of the central region, relatively densely populated but the most economically developed of eastern areas and the less developed western region relatively sparse population and economy.

TABLE 8 | Estimated results of the agglomeration by region.

Variables	Types of effects	The eastern region		The central region		The western region	
		Parameter estimation	T-test value	Parameter estimation	T-test value	Parameter estimation	T-test value
Ln*AGG*	Sde	0.150	1.59	0.054	0.87	−0.345***	−5.37
	Sse	−0.357	−0.86	0.885**	2.26	−1.262**	−2.50
	Lde	0.391*	1.65	0.077	0.70	−0.597	−0.47
	Lse	−0.642	−1.14	0.988**	2.11	0.065	0.05
Ln*AGG_SQ*	Sde	0.010	1.24	0.010	1.41	0.038***	4.62
	Sse	0.020	0.62	−0.126***	−2.84	0.191***	3.17
	Lde	−0.026	−1.27	−0.015	−1.20	0.066	0.48
	Lse	0.038	0.84	−0.139***	−2.61	0.010	0.07

*Note: *p < 0.1, **p < 0.05, ***p < 0.01. Sde is short-term direct effect. Sse is short-term spillover effect. Lde is long-term direct effect. Lse is long-term spillover effect.*

According to **Table 8**, the relationship between *AGG* and *GTFP* still shows a "U-shaped" curve. Specifically, *AGG* in the eastern region does not have a significant spillover effect on the surrounding areas. As the region with the highest level of economic development in China, the eastern region has relatively abundant resources. This causes competition between the cities in the eastern region greater than cooperation (Zelai, 2009). It blocks the spatial spillover effect of the agglomeration externalities to a certain extent. The estimation result of *AGG* in the central region is similar to that in the eastern region. But the difference is that the *AGG* in the central region not only has an impact on the *GTFP* of the region but also has a significant spatial spillover effect on the surrounding areas. The possible reason is that the central region, as the undertaking ground of industrial transfer, needs to utilize the labor resource endowments of different cities. The close connection between the cities accelerates the spillover effect of knowledge and facility sharing. Although the economic agglomeration activities in the western region have also produced obvious spatial spillover effects, their direction of action is opposite to that in the central region. The possible reason is that the western region is more agglomerated of the secondary industries. A large and comprehensive layout can easily lead to blind investment and redundant construction (Lan et al., 2021).

5.5.3 Time-Segment Heterogeneity Test

The emergence and development of an urban system are the results of the joint action of the centripetal force and centrifugal force. For a long time, people seem to have the idea that high-density economic activities are the root cause of increased energy consumption, environmental quality, and various urban diseases. However, we hold a different view. Considering the various positive externalities of agglomeration, *AGG* may be an important way to realize green development. The motivation of energy conservation, emission reduction, and environmental governance may also become the "centripetal force" of *AGG*.

Since 2000, various provinces and cities have successively initiated the reform of the Hukou registration system. The reform aims to attract surplus rural labor to urban. The last area to implement the reforms was Chongqing (2010). To test the impact of the reform on *AGG* and *GTFP* we use 2010 as the boundary and divide the sample into two periods: 2003–2010 and 2011–2018. The impact of *AGG* on the dynamic space of *GTFP* before and after the implementation of the policy is discussed. **Table 9** reports the corresponding estimation results. From the overall trend, in the two periods, the relationship between *AGG* and *GTFP* still shows a "U"-shaped curve. However, after 2010, the impact of *AGG* on *GTFP* of the surrounding areas has turned from negative to positive. From the perspective of the degree of influence, the estimated value of the effect parameter of *AGG* in 2003–2010 is significantly lower than that in 2011–2018. It means that since the reform of the Hukou registration system, the local governments have relaxed their obstacles to *AGG*. This promoted the redistribution of the economic geography, increased the degree of agglomeration, and enabled some cities to cross the threshold. This is consistent with the research conclusion of Cui et al. (2022). From the perspective of the final effect, the impact and significance of *AGG on* the GTFP have been further improved after the "population mobility restriction" was relaxed.

6 CONCLUSION AND POLICY IMPLICATIONS

6.1 Research Conclusion

China's economy has made great strides, but with the economic development has come the natural resource depletion serious environmental pollution. China now ranks second globally in GDP, but it ranks first in terms of both pollutant emissions (CO_2, SO_2, $PM_{2.5}$, and oxynitride) and primary energy consumption. This has forced China to change modes from traditional development to green development. The three key factors in green development are economic development, resource conservation, and environmental protection. When rapid development occurs, the degree of economic agglomeration also increases. However, there are no consensus empirical studies about how economic agglomeration affects economic growth and environmental quality. This raises the question of how economic agglomeration will affect green economy efficiency, as measured by an index that comprehensively considers economic growth, resource conservation, and environmental protection. The answer to this question will help formulate industrial policies, achieve the goals of energy conservation and emission reduction, and contribute to China's sustainable future development.

TABLE 9 | Estimated results of the agglomeration by time-segment.

Variables	Types of effects	From 2003 to 2010		From 2011 to 2018	
		Parameter estimation	T-test value	Parameter estimation	T-test value
Ln*AGG*	Sde	−0.118*	−1.94	−0.183***	−3.03
	Sse	−0.593	−0.39	0.610	1.12
	Lde	−0.159	−1.27	−0.289***	−3.04
	Lse	−0.611	−0.37	0.787	1.20
Ln*AGG_SQ*	Sde	0.012**	2.44	0.014**	2.02
	Sse	0.040	0.23	−0.067	−1.44
	Lde	0.016**	1.97	0.021**	2.03
	Lse	0.040	0.21	−0.084	−1.50

*Note: *p < 0.1, **p < 0.05, ***p < 0.01. Sde is the short-term direct effect. Sse is the short-term spillover effect. Lde is the long-term direct effect. Lse is the long-term spillover effect.*

We have constructed a theoretical model that can describe the relationship between economic agglomeration and green TFP. Under the super-efficiency DEA framework, the NDDF is used to calculate a green TFP that comprehensively considers economic growth, resource conservation, and environmental protection. The panel data of 281 prefecture-level and abovementioned cities in China from 2003 to 2018 are used. Based on the quantitative analysis techniques such as the dynamic SDM model and mediation effect model, the impact of the economic agglomeration on the green TFP and the spatial spillover effect is tested. Several possible influence paths have been found and verified. Finally, robustness test and heterogeneity analysis were carried out. The results are as follows:

1) The green TFP has a strong space-time dependence effect. In the time dimension, if the green TFP of the previous period was at a high level, the next period may also continue to rise. In the spatial dimension, the green TFP between the regions shows a significant positive spatial correlation effect. In terms of time and space, the current poor performance of the green TFP in this region has a clear "warning effect" on the next green TFP development in the neighboring regions.
2) The impact of economic agglomeration on the green TFP has two ways, direct and indirect. As far as the direct impact is concerned, the relationship between economic agglomeration and green TFP both shows an obvious "U"-shaped curve. When the degree of economic agglomeration is low, the gathering suppresses the green TFP. But when the economic agglomeration exceeds the threshold, it shows a clear promotion effect on the green TFP. As far as indirect effects are concerned, "low-quality agglomeration of the secondary and tertiary industries" and "restrictions on the population mobility" are important reasons that economic agglomeration fails to produce a positive spatial spillover effect on the surrounding areas.
3) Economic agglomeration has a threshold effect on the impact of agglomeration externalities such as infrastructure sharing, knowledge spillover, and advanced labor market. This is the inherent reason for the "U-shaped" curve relationship between economic agglomeration and green TFP. When the degree of economic agglomeration is low, the abovementioned three types of agglomeration externalities are not yet obvious. When the degree of agglomeration exceeds the threshold, these three paths can play a vital role in promoting the effective communication and exchange of information, reducing the cost of information transmission, promoting the formation of economies of scale, and controlling pollutants.

6.2 Policy Implications

The policy implications of the abovementioned conclusions are embodied in the following two aspects.

1) We should promote the rational allocation of the human resources in space. The traditional concept believes that the agglomeration of economic activities is the root cause of the increase in energy consumption and environmental pollution. This view weakens the potential energy-saving and emission reduction effects of economic agglomeration itself. Our conclusions show that when the economic agglomeration reaches a certain level, the spatially concentrated production mode of the economic activities has obvious green attributes compared to the dispersed production mode. This means that the city's economic development strategy and green transformation goals can achieve wonderful implementation effects under certain conditions. At present, problems such as high energy consumption and high pollution in cities are more prominent. This may be because the economic agglomeration is at a low-level stage, and its positive externalities are not yet obvious. We believe that as the level of economic agglomeration continues to increase, its inherent green effect will appear on a larger scale. Therefore, we should continue to promote the development of an agglomeration economy and promote the formation of a coordinated linkage mechanism between the regions. The spatial concentration of the economic activities is increased, and economic agglomeration is brought to an ideal stage where it can exert a significant green effect.
2) A green development strategy is formulated rationally based on the characteristics of the city. In the small city, it is necessary to rely on the surrounding large and medium

cities to develop a green economy through the improvement of urban infrastructure construction and industrial cooperation. For the medium-sized cities, resource and infrastructure carrying capacity must be considered. Attention should be paid to cultivating the momentum of urban agglomerations. It should take resource conservation and environmental friendliness as the prerequisite and promote moderate-scale urbanization through the reform of the Hukou registration system. For the large cities, it is necessary to promote integrated development of cities and towns, exerting the gathering effect and divergence function. The agglomeration effect brought about by the concentration of economic activities by improving the allocation of the urban public resources is maximized.

However, regardless of the positive results, there are still some limitations. Green TFP is a complex system with multiple levels and multiple structures. The index calculated by the NDDF model is a simple simulation of the entire system, and further research is needed to develop a more robust evaluation system. In addition, as the application of the green TFP indicators, its impact on sustainable development is also an area of related research. Many areas can be further studied in the future, such as the impact on poverty alleviation and ecological optimization.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

Conception and design of the study: HA-m and TJ-y. Acquisition of data: RZ and TJ-y. Analysis and interpretation of data: TJ-y. Drafting the manuscript: TJ-y. Revising the manuscript critically for important intellectual content: HA-m and TJ-y.

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SUPPLEMENTARY MATERIAL

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Forest tourism development conflict analysis under carbon peak and neutrality goals—Based on graph model for conflict resolution

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To achieve carbon peaking and carbon neutrality goals, maintaining forest savings has become the key. How to reduce the damage of forest tourism development to the environment, reconcile conflicts, and promote the orderly implementation of forest tourism projects while maintaining forest savings is an important prerequisite for the development and construction of forest tourism. First, we constructed a fundamental Graph Model for Conflict Resolution (GMCR) during forest tourism development under carbon peak and neutrality goals. From the perspective of the dynamic interaction of conflict analysis, this article explains the game behavior behind the conflict of forest tourism development. Next, we calculated the equilibrium solution of a three-party game which means tourism enterprises adopt compensatory strategies, local residents support forest tourism development, and the government supports tourism enterprises for development projects, develops an ecological compensation system, and strengthens supervision. It provides a set of systematic and effective conflict analysis tools for stakeholders of forest tourism development projects and provides decision-making and reference information for the formulation of similar environmental resource development policies.

KEYWORDS

forest tourism development, conflict analysis, graph model for conflict resolution, China, carbon peak and neutrality goals, game

1 Introduction

As the contradiction between environmental protection and social and economic development becomes more and more intense, the Kyoto Protocol, the Paris Agreement, and other conferences and agreements have emerged in order to reduce carbon emissions and seek sustainable development of the Earth's ecology (Ding and Wang, 2020). On 22 September 2020, at the General Debate of the Seventy-fifth United Nations General Assembly, General Secretary Xi Jinping proposed: "China's carbon dioxide emissions must reach the peak by 2030 and strive to achieve carbon neutrality by 2060" (Liu, 2020).

Making this major strategic decision demonstrates China's determination and efforts to deal with global climate issues and also provides a direction and a starting point for China to accelerate the construction of ecological civilization and high-quality development (Gao and Yu, 2021). Forests have a carbon sink function (Xi and Li, 2006), and forest carbon sinks are an important strategy for China to deal with global climate issues (Zhang and Chen, 2021). Therefore, the protection of forest deposits has received widespread attention. In addition to its ecological value, forest tourism resources can also provide tourists with economic values such as recreation and forest health. Therefore, forest tourism is welcomed by more and more tourists (Zhang, 2017). As a result, more and more tourism enterprises are interested in developing forest tourism resource projects in forest areas with conditions, which has brought considerable economic benefits to the local economy (Jia and Liu, 2020). However, forest tourism resources are very limited in their ability to decompose and purify waste and recover from ecological damage (Yang et al., 2011). Socio-economic development and changes in human activities can easily destroy forest resources, such as fires caused by changes in human activities (Pereira et al., 2005). The tourism activities of forest tourists will produce a tourism carbon footprint, and the development of tourism projects will also destroy forest tourism resources to a certain extent, resulting in a reduction in forest savings (Wang et al., 2018). At the same time, the forest tourism development process will encroach on cultivated land and woodland of local residents, and even force residents to leave their homes. Although tourism development can promote the development of the local economy, the intervention of external investors and the government may crowd out the interests of local residents. When local residents lose control over tourism, their ability to develop in other industries such as agriculture and fisheries will also be affected (Greenwood, 1972). As the literature (Lopes et al., 2015) found when studying how fisheries and tourism in southeastern Brazil interact with nature conservation, resources in a certain area are limited. To achieve non-conflicting use of environmental resources between tourism development and other industries, a fee for environmental services is needed. In addition, the external environmental costs, such as cultural invasion and environmental destruction caused by the influx of a large number of tourists, have increased residents' expenditures (Liu and Zhao, 2021). In practice, residents have not been compensated for the increase in external environmental costs, which has caused constant conflicts among many stakeholders in the process of forest tourism development (Yi, 2011). Faced with the demanding background of China's "dual carbon" goal, the conflict of forest tourism development needs further attention and resolution. The concept of conflict originates from sociology and reflects the most common phenomenon in social life, which refers to the way or process of fierce social interaction between individuals or groups (Chen, 2000), manifested in contradictions or tensions in mutual relations and even confrontations behavior (Cornet, 2015; Xie, 2019). Under the background of the "dual carbon" goal, all kinds of social activities begin to emphasize low-carbon and environmental protection (Liu et al., 2020), and inappropriate forest tourism development will destroy local forest resources, reduce forest savings, and affect the normal life of local residents. Enterprises hope to develop forest tourism projects at the lowest cost, while local residents do not want forest tourism development to affect the local environment and residents' lives. On the one hand, the government hopes that enterprises will bring more economic benefits to the development of forest tourism projects; on the other hand, it also hopes to achieve the carbon emission reduction target, which leads to the conflict of interests between local residents, forest tourism development enterprises, and the government. If this conflict cannot be properly resolved, on the one hand, the local residents will not cooperate or even hinder the confrontation of project development, construction, and management, and the development of local forest tourism industry will be difficult to achieve; on the other hand, improper forest tourism resource development activities of enterprises, such as extensive development and blind occupation of land for development without reasonable planning, will damage local forest resources and ecological environment, reduce forest savings, and be not conducive to the realization of the "dual carbon" goal.

Previous studies on conflicts in the field of tourism were mostly based on stakeholder theory. The contradictions and conflicts among stakeholders related to the tourism industry were mostly based on uneven distribution of interests and imbalance of the right structure. In the process of tourism development, the causes of conflicts are incompatible economic demand (Dredge, 2010; Li et al., 2020), differences in attitudes or values (Brown and Raymond, 2014), and unsound management systems (Ji et al., 2012). Literature (Zhang, 2013) uses the classical game method, and this study analyzed the game process between tourism enterprises and community residents and found that it is the contradiction caused by the difference in interest demands of both sides. Literature (Tang, 2020) points out that in the face of the conflict between enterprises and residents caused by an uneven distribution of interests, it is necessary to optimize the way of interest distribution and change the differences of interests to build a tourism interest community. From the perspective of decision-makers, there are mainly pairwise games between enterprises and residents, residents and tourists, governments and enterprises, and villagers and villagers (Tang, 2020). Some scholars have jointly considered the multiple subjects of local governments, tourism enterprises, and community residents. Others have also included tourists in the game category and constructed a multi-party game framework (Li and Zhao, 2020). In terms of methods, stakeholder analysis in the field of tourism is mainly based on classical game methods (Li et al., 2020), and some scholars conduct quantitative analysis based on data collection (Kuvan and Akan, 2012; Nguyen et al., 2022). The contradictions of interest distribution and status differences among stakeholders in the existing literature have laid a theoretical foundation for this study. However, the core of the existing research is the balance of interest distribution, and there is less analysis based on the goal of low-carbon environmental protection and much less conflict analysis in the field of forest tourism. Graph Model for Conflict Resolution (GMCR) is an extension of Classic Game Theory and Partial Game Theory. It mainly conducts a formal and effective analysis of conflict behaviors between decision-makers to help decision-makers analyze the optimal decision plan (Fang et al., 1989). Graph Model for Conflict Resolution (GMCR) combines quantitative and qualitative analysis methods and uses set theory and graph theory to present the generation, development process, and final results of conflict behavior in social life in a mathematical modeling manner (Hou and Xu, 2016). Compared with game theory, the conflict analysis model requires less data and information and is more practical (Kilgour et al., 1987; Han et al., 2022).

Therefore, the study took the forest tourism development conflict as the research object to solve the conflict problem in the forest tourism development under the background of "dual carbon" through the Graph Model for Conflict Resolution (GMCR) and provided analysis tools and basis for decision-making for resolving the conflict between the various stakeholders in the forest tourism development. This article includes the following parts: First, based on the background of forest tourism development conflict, we clarified the main strategies, feasible states, and state transition diagrams of forest tourism development stakeholders. Second, we identified and ranked the preferences of different stakeholders. Third, based on strategy and preference information, software was used to solve the equilibrium solution of forest tourism development conflict. Fourth, we drew conclusions and put forward countermeasures and suggestions to solve the conflict of forest tourism development.

2 Research method

2.1 Graph Model for Conflict Resolution (GMCR)

Forest tourism development involves multiple stakeholders. Considering that the information on different subjects is difficult to obtain in the actual development process, the lack of real data information leads to the reduction of the applicability of the quantitative model. Therefore, a more adaptable Graph Model for Conflict Resolution (GMCR) method is adopted. The model does not require complex data and can draw research conclusions by analyzing the preference information of various stakeholders, combining the dual advantages of qualitative and quantitative analysis. Decision-makers and strategies, feasible states, state transition graphs, and preference information are the four core elements of the Graph Model for Conflict Resolution (GMCR) (Zhao et al., 2016). The construction of a basic diagram model of forest tourism development conflicts under the background of the "dual carbon" target needs to be based on the background of the conflict problem and reflect the aforementioned four core elements.

2.1.1 Conflict problem background

Forest tourism development is based on the development process that forest tourism resources provide consumers with forest-related tourism products (He, 2010). The forest tourism development conflict involves the three main stakeholders: the forest tourism development enterprise, local residents, and the government. Forest tourism development enterprises will occupy local residents' woodland, arable land, and houses when constructing facilities required for forest tourism projects and delineating tourism activities. Some residents may be forced to leave the long-term living environment. Furthermore, tourism development will destroy the local ecological environment to a certain extent and reduce local forest deposits. Economic losses and environmental losses coexist. In such a situation, it is inevitable for local residents to oppose and even confront the development activities of forest tourism enterprises when facing the infringement of forest tourism development on their own economic and environmental interests. The opposition from local residents is the core of forest tourism development conflicts. Adopting reasonable strategies to obtain support from local residents is the key to the implementation of forest tourism development projects.

For forest tourism development enterprises, facing the pressure of the "dual-carbon" target background, on the one hand, they can continue to adopt the traditional forest tourism development model, that is, non-protective development. The development cost of this development method is lower, but the protective use of the environment is ignored, which is more likely to conflict with local residents, causing resistance and non-cooperation from local residents, making it difficult to maintain development projects. On the other hand, forest tourism development enterprises can follow corresponding standards and adopt protective development strategies. The development of forest tourism products and the construction of tourism facilities on the premise of protecting the forest ecological environment and maintaining forest deposits will help to win the support of local residents and all walks of life, but at the same time, it needs to bear higher protection and development costs. It is contrary to the characteristics of the enterprise's purpose of profitability. In addition, forest tourism development enterprises can also adopt compensatory development to provide local residents and the government with a certain amount of economic compensation while carrying out forest tourism development and construction. On

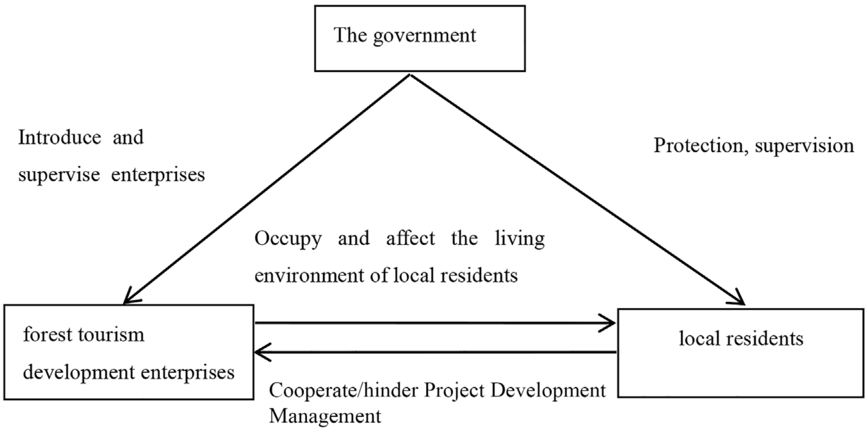

FIGURE 1
Frame graph of the relationship between main interests of forest tourism development.

the one hand, it makes up for residents' sense of deprivation in the process of forest tourism development. On the other hand, local governments and residents can use this compensation income to repair the environmental damage caused by forest tourism development, to a certain extent, to meet the purpose of forest protection. The government must not only play the role of attracting investment to promote local economic development but also uphold the concept of ecological civilization, maintain the local ecological environment, and take the path of sustainable development. In addition, out of the need for political performance, the government is more inclined to place external industrial and commercial capital in places, use local characteristic resource development projects to revitalize the industry, and provide more employment opportunities and sources of income for the local area. Therefore, the government generally supports the development of forest tourism development projects. However, in view of the pressure of low-carbon environmental protection and the pressure of local residents, the government can adopt an ecological compensation system and strengthen supervision strategies to reconcile conflicts and promote the implementation of tourism development projects. In view of the background of the conflict issue, the excellent tourism development stakeholder relationship framework is summarized as shown in Figure 1.

2.1.2 Decision-makers and strategies

According to the description of the conflict background, the forest tourism development conflict under the "dual carbon" target background mainly includes three decision-makers. They are the forest tourism development enterprises (DM1), local residents (DM2), and the government (DM3).

(1) Main strategies of forest tourism development enterprises

Forest tourism development enterprises aim to maximize the profits of enterprises and obtain higher profits by vigorously developing forest tourism resources, developing forest tourism projects and tourism products, and promoting consumer consumption. At the same time, tourism enterprises also need to assume social responsibilities. They adopt pro-environmental behaviors and maintain good cooperative relations with local residents and governments based on the reputation mechanism and feasibility of the project. Therefore, the main strategies of forest tourism development enterprises are as follows.

The first is non-protective development. During the development and construction of forest tourism projects, planning, construction, operation, and management aimed at the lowest cost may pollute the local ecological environment, destroy forest resources, and affect the normal production and life of local residents.

The second is protective development. Based on the natural environment and socio-economic status of the forest area, under the scientific guidance of ecology, landscape science and ethics, planning, construction, operation, and management are carried out on the basis of not damaging the local forest ecology and not affecting the daily life of local people. Clean energy, energy-saving products, and environmental protection products should be used in the development and construction process, and the generated waste should be disposed of harmlessly.

The third is compensatory development. On the basis of non-protective development, the local government and residents should be given certain economic compensation. On the one hand, the exclusion psychology of local residents can be reduced. On the other hand, the government can use this economic compensation to restore the damage and pollution caused by the development of forest tourism projects.

The fourth is abandoning development. If the forest tourism development enterprise receives strong opposition from residents, when the conflicts between the parties are difficult to reconcile, and the cost-benefit ratio of the forest tourism development project is too low, the enterprise will choose to abandon the development, that is, to cancel the local forest tourism development project.

(2) Main strategies of local residents

For local residents, the process of forest tourism development will bring a sense of deprivation to local residents. Their original living environment will be changed. Traditional ecological resources and cultural awareness will also be impacted by outsiders, which destroys their traditional living habits. Forestry products that could originally bring economic benefits will also be restricted and will not be able to obtain benefits within a certain period of time. Therefore, the main strategies of local residents are as follows.

The fifth is opposing the development of forest tourism. Convey dissatisfaction and opposition to the government and enterprises about the messages that forest tourism development enterprises and forest tourism projects do not cooperate or even hinder the construction and management of forest tourism development projects.

(3) The main strategy of the government

For the government, the development of forest tourism is an important opportunity to develop the multi-functional value of rural forest areas and revitalize the forest industry (Li, 2019). The public choice theory believes that from a certain perspective, the government can be regarded as an economic man with certain self-interested behavior motives and certain profit-seeking characteristics (Qiao and Wang, 2002). Therefore, it is an inevitable choice for the government to promote the development of forest tourism. In reality, the government is often the promoter of tourism development and the introduction of forest tourism development enterprises. However, the government also needs to assume social responsibilities. Protecting the ecosystem of forest areas and maintaining forest savings are also responsibilities that the government cannot ignore. Therefore, the main strategies of the government are as follows.

The sixth is supporting the development of forest tourism by tourism enterprises. Strengthen the comprehensive compensation system for forest ecological benefits, formulate preferential policies for tax reduction and exemption based on preferential investment policies and preferential policies for the establishment of forest tourism construction projects, strengthen forest tourism publicity, and increase public opinion support.

The seventh is formulating an ecological compensation system and strengthening supervision. Amplify a comprehensive compensation system for forest ecological benefits, preferential policy for investment, preferential policy for tax reduction and exemption, preferential policy for project approval of forest tourism construction projects, public opinion and consumption-oriented support, and so on. Formulate the ecological compensation and economic compensation system and management measures for forest tourism development, clarify the liability and scope of compensation, clarify the scope of ecological and social responsibilities that enterprises should undertake, and set up a special project management team to supervise the planning, construction, operation, and management activities of enterprises, and supervise enterprises to implement the economic compensation to residents and local governments.

2.1.3 Feasible state

According to the aforementioned analysis, the three main decision-makers of forest tourism development have a total of seven strategies, and the corresponding decision-makers of each strategy have two attitude expressions, including "Y" and "N", which are represented by different decision-makers. The situation is obtained by different decision-making attitudes of different decision-makers. Graph Model for Conflict Resolution (GMCR) calls this situation a state (Kilgour et al., 1987). Based on this, there are a total of 2^7 states of forest tourism development conflicts, but not all states are feasible in reality. For example, forest tourism development enterprises cannot choose between protective and non-protective development strategies at the same time. There is another category that no matter what the residents and the government choose, forest tourism development enterprises will abandon the development of forest tourism. Eliminating the infeasible states, it is as shown in Table 1 that there are 19 feasible states of forest tourism development conflicts. The "-" in S19 means that no matter what strategy other decision-makers adopt, forest tourism development enterprises will choose to give up development.

2.1.4 State transition graph

State transition refers to the fact that decision-makers adjust their own strategies to make their own decision-making state change without considering the other decision makers' changing strategies. The state transition graph reflects the game interaction process of decision-makers (Zhao et al., 2016). According to the feasible state table, the state transition graph of the forest tourism development conflict under the "dual carbon" goal is drawn, as shown in Figures 2–4. The circles in the figure represent the feasible states. The arcs connect different feasible states, and the arrows of the arcs indicate the transition direction of the states (Zhao et al., 2016; Zhang et al., 2019).

2.1.5 Preference information

The strategic priority ranking method is used to rank the state preferences of forest tourism development conflicts (Fang et al., 2003a). The option prioritization requires that prior to ranking, a corresponding set of preference statements should be

TABLE 1 Feasible state.

Decision-makers	Strategies	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}	s_{11}	s_{12}	s_{13}	s_{14}	s_{15}	s_{16}	s_{17}	s_{18}	s_{19}
Forest tourism development enterprises (DM1)	1. Non-protective development	Y	N	N	Y	N	N	Y	N	N	Y	N	N	Y	N	N	Y	N	N	—
	2. Protective development	N	Y	N	N	Y	N	N	Y	N	N	Y	N	N	Y	N	N	Y	N	—
	3. Compensatory development	N	N	Y	N	N	Y	N	N	Y	N	N	Y	N	N	Y	N	N	Y	—
	4. Abandoning development	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y
Local residents (DM2)	5. Opposing the development of forest tourism	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y	N	N	N	Y	Y	Y	—
Government (DM3)	6. Supporting the development of forest tourism	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	—
	7. Formulating an ecological compensation system and strengthening supervision	N	N	N	N	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	—

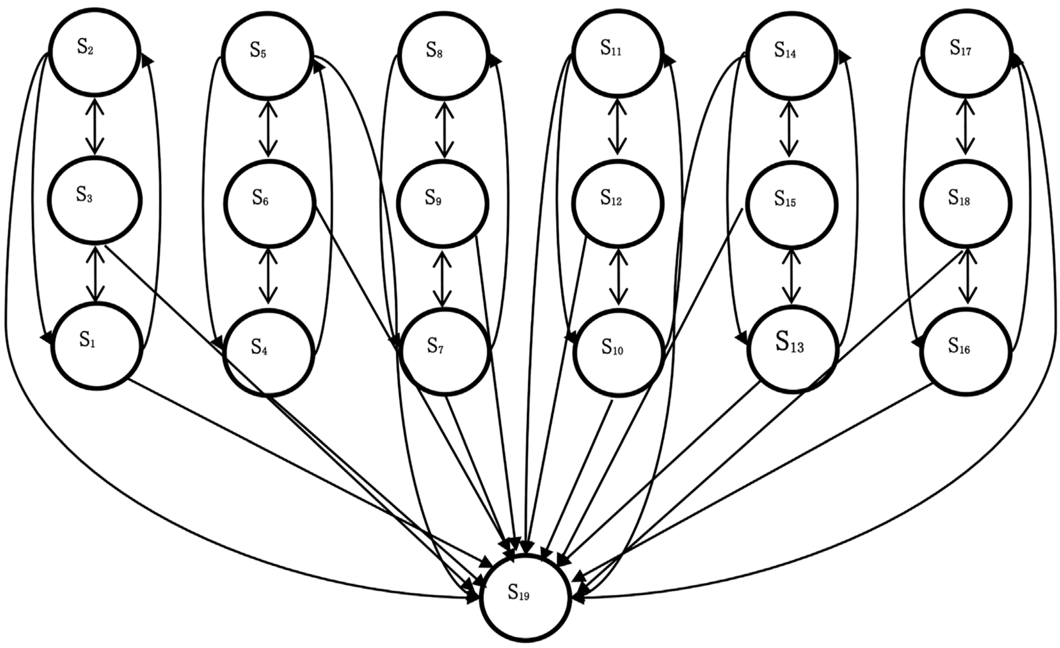

FIGURE 2
Forest tourism enterprise state transition graph.

given according to the specific preference information of each decision-maker, and the decision maker's preference sequence can be obtained based on the preference statement information (Fang et al., 2003b). According to the analysis background of forest tourism development conflicts, the preference statement information of forest tourism development enterprises, local residents, and governments in forest tourism development conflicts can be obtained through analysis, as shown in Table 2.

From the preference statement information in Table 2, according to the strategic priority ranking method, the state preference sequence of the tripartite decision-makers involved in forest tourism development conflicts is as follows.

(1) Preference sequence of forest tourism development enterprises (DM1)

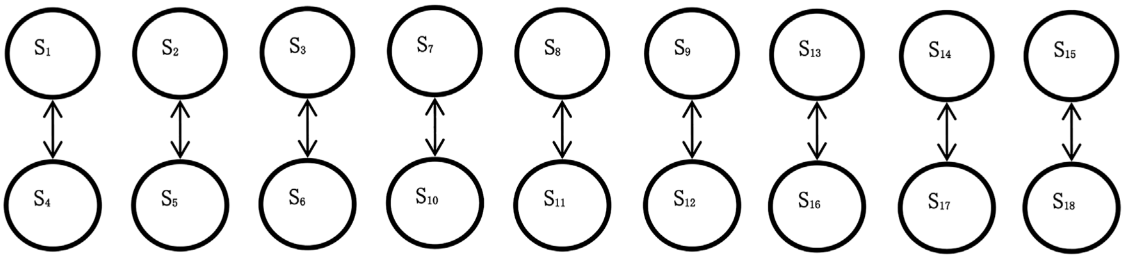

FIGURE 3
Local residents' state transition graph.

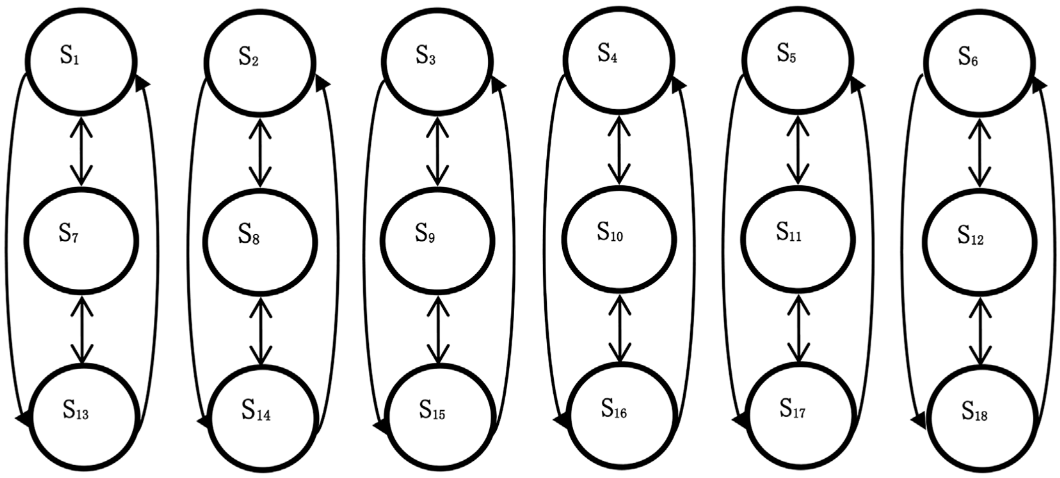

FIGURE 4
Government's state transition graph.

S7>S13>S9>S15>S1>S3>S10>S16>S12>S18>S4>S6>S8>S14>S2>S11>S17>S5>S19.

(2) Preference sequence of local residents (DM2)

S14>S17>S8>S2>S5>S11>S15>S18>S3>S9>S6>S12>S19>S16>S13>S4>S10>S7>S1.

(3) Preference sequence of government (DM3)

S8≻S14≻S11≻S17≻S5≻S2≻S18≻S15≻S6≻S3≻S9≻S12≻S19≻S13≻S16≻S4≻S10≻S1≻S7.

The result of the preference sequence shows that decision-makers related to forest tourism development prefer self-interested behavior. Compared with protective development or compensatory development, forest tourism development enterprises are more inclined to non-protective development with lower cost, while local residents are more inclined to forest tourism development enterprises to adopt protective development, and the second-best is to take compensation. The government hopes that forest tourism development enterprises will adopt protective development and that local residents can support the implementation of forest tourism development projects. Because the preferences of various stakeholders are heterogeneous and opposite, it will inevitably lead to the emergence of conflict in forest tourism development.

3 Stability analysis

Stability analysis refers to the final result obtained through conflict analysis of each decision maker's game. Through the software GMCRII, the decision maker's equilibrium strategy

TABLE 2 Preference statements and implications of decision-makers in forest tourism development.

Decision-makers	Statements	Explanation
Forest tourism development enterprise (DM1)	−4	Do not want to give up on development
	−2	Do not want protective development
	−5	Do not want local residents to oppose the development of forest tourism
	6	Hoping that the government will support the development of forest tourism
	1	Hoping for non-protective development
	−7	Do not want the government to formulate an ecological compensation system and strengthen supervision
	−3	Do not want to make compensatory development
Local residents (DM2)	2	Hoping that forest tourism development enterprises will carry out protective development
	−1	Do not want forest tourism development enterprises to carry out non-protective development
	−4	Do not want forest tourism enterprises to give up development
	3	Hoping that forest tourism development enterprises will carry out compensatory development
	7	Hoping that the government will develop an ecological compensation system and strengthen supervision
	−5IF2	If the forest tourism development enterprise conducts protective development, they will not oppose the development of forest tourism
	5IFF1	If and only if a forest tourism development enterprise conducts non-protective development, it is opposed to forest tourism development
Government (DM3)	2	Hoping that forest tourism development enterprises will carry out protective development
	−1	Do not want forest tourism development enterprises to carry out non-protective development
	−4	Do not want forest tourism enterprises to give up on development
	3	Hoping that forest tourism development enterprises will carry out compensatory development
	6IF2	Supporting forest tourism development if forest tourism development enterprises carry out protective development
	7IF1	Develop an ecological compensation system and strengthen supervision if forest tourism development enterprises conduct non-protective development
	7IF3	Develop an ecological compensation system and strengthen supervision if forest tourism development enterprises carry out compensatory development

results under the four basic stability definitions (Nash, GMR, SMR, and SEQ) are obtained (Wu et al., 2015), as shown in Table 3.

In Table 3, it refers to (Zhao et al., 2016) the use of symbols in conflict stability analysis, if a decision-maker meets a certain stability definition requirement, it uses "√" to indicate stability. If all decision-makers meet all stability definition requirements in a certain state and the state is stable, then the state is an equilibrium solution under the definition of stability. It is represented by "E" in this study and marked with "*" in the table.

In the process of forest tourism development, tourism enterprises do not want to give up development, nor do they want to adopt higher-cost protective development, and local residents will oppose forest tourism development only when tourism enterprises conduct non-protective development, and the government is committed to balancing the contradiction between the two and achieve regional economic benefits. Therefore, the state between the three will be transferred, and finally, the equilibrium state of S15 will be reached. From the analysis results in Table 3, it can be seen that the state S15 meets the four stability definition requirements (Nash, GMR, SMR, and SEQ) and achieves an equilibrium state (Wu et al., 2015). Therefore, S15 is the equilibrium solution for the forest tourism development enterprise, the local residents and the government after the conflict game, and it is the optimal choice obtained by each decision-making party after the game. State S15 indicates that forest tourism development enterprises adopt compensatory development, local residents support forest tourism development, and the government supports tourism enterprises forest tourism development, formulates an ecological compensation system, and strengthens supervision. From the preferences of enterprises and residents, it can be seen that both are self-interested actors, and they are more inclined to adopt strategies that are more beneficial to themselves. The low-cost self-interested strategies adopted by enterprises, such as non-protective development, will deprive and encroach on local residents' reasonable rights. Therefore, the core motivation for forest tourism development conflict is the self-interested behavior preference of the conflicting parties. Although the government is also the subject of self-interest to a certain extent, the government is also the subject of altruistic behavior at the same

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TABLE 3 Stability analysis results of forest tourism development conflict.

State	Nash				GMR				SMR				SEQ			
	DM1	DM2	DM3	E	DM1	DM2	DM3	E	DM1	DM2	DM3	E	DM1	DM2	DM3	E
S1		√	√		√	√	√	*	√	√	√	*	√	√	√	*
S2						√	√			√	√					
S3	√	√			√	√	√	*	√	√	√	*	√	√	√	*
S4			√		√	√	√	*	√	√	√	*	√	√	√	*
S5		√				√	√			√	√			√		
S6						√	√			√	√			√	√	
S7		√	√		√	√	√	*	√	√	√	*	√	√	√	*
S8						√	√			√	√					
S9	√	√			√	√	√	*	√	√	√	*	√	√	√	*
S10			√		√	√	√	*	√	√	√	*	√	√	√	*
S11		√				√	√			√	√			√		
S12	√				√	√	√	*	√	√	√	*	√	√	√	*
S13		√	√		√	√	√	*	√	√	√	*	√	√	√	*
S14			√			√	√			√	√				√	
S15	√	√	√	*	√	√	√	*	√	√	√	*	√	√	√	*
S16			√		√	√	√	*	√	√	√	*		√	√	
S17		√	√			√	√			√	√			√	√	
S18	√		√		√	√	√	*	√	√	√	*	√	√	√	*
S19																

time, and government behavior has significant external characteristics. From the analysis process of forest tourism development conflict, it can be seen that, on the one hand, the government supports the forest tourism development projects of tourism enterprises, which is self-interested. By formulating an ecological compensation system and strengthening supervision, it has a strong tendency for altruistic behavior. The government formulates an ecological compensation system and strengthens supervision can prompt enterprises to adopt a compromised development strategy and then guide the behavior of local residents, making the final state a stable state S15. In this state, the conflicting parties become the main body of mutually beneficial behavior, which not only preserves their own interests but also maximize comprehensive benefits through mutual benefit.

4 Conclusion and recommendations

To achieve the "dual carbon" goal, maintaining the amount of forest savings is the key. How to reduce the environmental damage caused by forest tourism development, reconcile conflicts, and promote the orderly implementation of forest tourism development projects while maintaining forest savings is the important premise of the development and construction of forest tourism. Graph Model for Conflict Resolution (GMCR) is introduced into the research field of forest tourism development conflicts under the background of "dual carbon" goals, and Graph Model for Conflict Resolution (GMCR) method is used to analyze and solve the conflicts between stakeholders on forest tourism development and construction. In this study, we constructed a basic graph model of forest tourism development conflicts under the background of "dual carbon" goals and obtained a balanced solution to the game among all parties in the conflict. That is, forest tourism development enterprises choose compensatory development strategies, local residents choose to support forest tourism development strategies, and the government select to support forest tourism development projects of tourism enterprises and formulate ecological compensation systems and strengthen supervision. At this time, all parties to the conflict have maintained their own interests to a certain extent. The conflict situation has been eased, and a stable development and construction environment has been provided for the implementation of forest tourism development projects. At the same time, it also provides the basis to achieve the "dual carbon" goal, maintain forest savings and realize the protection of forest tourism resources in the development. Based on the theory of Graph Model for Conflict Resolution (GMCR), the research framework of forest tourism development conflict is constructed. Based on the perspective of conflict game theory, the interest game behavior and interaction process among decision-makers in forest tourism development are simulated to explain the ecological compensation system and supervision mechanism of forest tourism development, which provides decision-making and reference information for similar environmental resource development policies.

According to the conflict analysis of forest tourism development, facing the background of the "dual carbon" target, the following suggestions are made.

First, the government should play a leading role in reconciling conflicts. According to the analysis of the aforementioned forest tourism development conflicts, it can be seen that, on the one hand, the government is an important subject in the game of interests and has a certain degree of self-interested behavior motivation. But on the other hand, the government will also play an important role in coordinating forest tourism development conflicts between forest tourism development enterprises and local residents to a certain extent. Therefore, facing the background requirements of the "dual carbon" goal, the government should play its leading role to coordinate the interests and interactions of all parties in the process of forest resource development and guide conflict situations to a cooperative situation. 1) The government should formulate a complete forest tourism development ecological compensation system and establish a complete supervision and management mechanism to supervise and manage tourism enterprises, restrict their occupation of natural resources and the living environment of local residents, and promote enterprises to adopt a compromise development strategy can also ensure the interests of local residents, make the final state of the game move to a stable state, and provide a guarantee for the joint realization of the "dual carbon" goal. 2) The government should do a good job in public services and market publicity, provide the necessary support for tourism enterprises, and promptly intervene in conflicts and disputes in tourism development. The government strengthens publicity to guide corporate behavior for eliminating environmental damage and enhances corporate responsibility for resources and the environment. The government should guide the biased perception of local residents and allow them to see that the development of forest tourism can be developed under protection and it can bring employment opportunities and channels for increasing income.

Second, tourism enterprises should cultivate their own environmental sensitivity. 1) If an enterprise adopts a low-cost self-interest strategy, it will deprive and encroach on the reasonable rights and interests of local residents. Therefore, tourism enterprises should take the initiative to learn, understand China's "dual-carbon" target requirements, and enhance the level of awareness of carbon compensation. Tourism enterprises take the initiative to assume environmental responsibilities in the process of forest tourism development and construction, pay attention to social reputation, and pay attention to environmental protection in development and construction and actively coordinate the relationship with local residents. Tourism enterprises build a good external environment in the development and construction of forest tourism, thereby reducing the possibility of conflicts with local residents and the government. 2) Tourism enterprises should discover business opportunities from environmental protection. Tourism enterprises should pay attention to the development trend of eco-tourism and consumers' demands for pro-environmental behaviors. While adopting protective development, they should also transform marketing logic, locate eco-tourism groups, and turn the cost of protective development of forest resources into operating advantages, thereby reducing conflict problems brought about by enterprises pursuing economic benefits.

Third, local residents should actively participate in and strengthen the alliance to enhance their right to speak. To a certain extent, tourism development competes with local residents for limited survival resources, which is the source of conflict between enterprises and residents (Shen and Wen, 2021). In order to resolve conflicts and reduce the negative effects of conflicts, local residents should actively participate in the decision-making and management process of forest tourism development in the face of forest tourism development and construction. 1) Local residents can use collective land and public forest resources and space to jointly develop forest tourism projects with tourism enterprises in the form of shares, turning conflicts into endogenous economic benefits, and transforming conflicting positions into common interests with the enterprise to resolve conflicts. 2) Residents should strengthen their alliances, enhance their voices, and participate in the development construction and management of forest tourism to restrict the non-protective behavior of enterprises and urge the development activities of tourism enterprises to meet their own development expectations.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding authors.

Author contributions

RZ and QC wrote the draft of the manuscript. RZ and YS contributed to data curation and analysis. QC and DK contributed to manuscript revision. All authors approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Green corridor: A critical perspective and development of research agenda

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The rapid development of industrialization, transportation, and urbanization has a negative impact on nature such as increased pollution, decreased pervious surface area, and increased temperatures. Researchers are consistently trying to find out ways that can facilitate the reduction of naturally unfriendly impacts. In this context, "green corridors" play a critical role. The main goal of the "green corridors" is to help build sustainable industrial, urban, and transportation networks by meeting requirements for environmental, technical, economic, social, and space planning issues. This paper provides a critical perspective on extant "green corridor" research by analyzing its performance and unwinding the intellectual structure. The perspective also sheds light on gaps in current literature and, therefore, possible future research avenues and calls for research in the field of "green corridor."

KEYWORDS

green corridors, sustainability, environmental science, development, global

Introduction

Urban ecosystem

The rapid development of industrialization, transportation, and urbanization in recent decades had a negative impact on nature (Zhang et al., 2019). Previous scholarship has reported that industrialization is playing the role of magnets in the increasing trend of people in urbanizations, where more resources, technology, major job opportunities, and facilities are available (Morya and Punia, 2022). This urbanization is the largest consumer of natural resources and producer of waste and pollution, which harm nature. Given the importance to nature, recent research specifies that urbanization has a negative impact on plant reproductive attainment as a result of altered habitat fragmentation and/or pollinator availability. It is widely acknowledged that enhancing ecological conditions for urban pollinators will likely increase reproductive success in insect-pollinated plants and facilitate interactions between urban plants and pollinators (Zhang et al., 2019). Moreover, El Adli and Abd El Aziz (2022) found that urban ecosystems experience numerous abiotic ecological changes, such as augmented pollution,

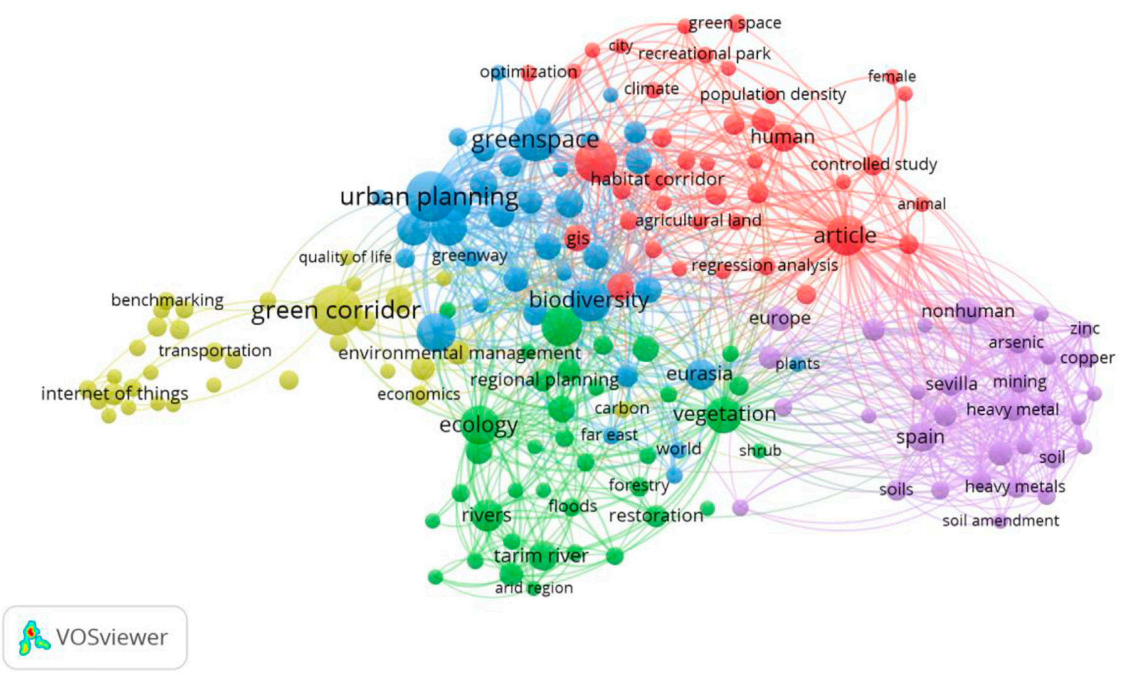

FIGURE 1
Co-word analysis of green corridor research.

decreased open surface area, and increased temperatures. These changes have negative impacts on nature. In this vein, green corridors are becoming increasingly important in nature protection.

Conceptual background of green corridors

The idea of green corridors came from Olmsted's "Parkways" in the United States and Ebenezer Howard's "Garden City" in England in the early 20th century. The goal of green corridors is to keep open spaces in cities and make sure they are connected. Aly and Amer (2010) defined "Green Corridor is networks of linked landscape elements that provide cultural, recreational, and ecological benefits to the community." Green corridors are linear open spaces, such as farmland, parks, or natural or seminatural areas, interwoven within or outside of urban areas to protect the environment and landscape (McMahon and Benedict, 2000; Ibrahim et al., 2022). People all over the world agree that green corridor systems are good for recreation, wildlife, and the environment and that they can bring many benefits to people who live in industrial and urban areas. The activities of green corridors provide transferable solutions to environmental, social, economic, and quality of life issues throughout the world.

The green corridors create a Green Network, which helps people relink with nature and provides instant and societal welfare (Che-Ani et al., 2012; Plantation and Pasoh, 2014). Green corridors are beneficial to the quality of life because they bring elements of nature into the urban environment and stimulate the senses through the use of sound, color, motion, and smell in relatively positive ways (Moreno et al., 2020). Instead, the primary purpose of each natural environment corridor is to facilitate environmentally friendly modes of transportation. Sustainable transportation systems can benefit from a dynamic greenway network. As a result, it serves as a conduit for the movement of people and things. In light of these benefits, green corridors are a subtle reply to global environmental sustainability.

There is evidence of evolving research in this context, however, when it comes to the unwinding of the intellectual structure of the research and providing future research avenues, studies are sparse. Some researchers have conducted a systematic review to identify possible research gaps but our study provides a perspective based on the panoramic view of the green corridor research in the past 30 years.

As concerns over sustainability are well recognized and encouraged by UNDP. From the perspective of green corridor sustainability, however, global development agencies are not playing an adequate role. The purpose of this perspective is to highlight that green corridor sustainability is not an automatic

TABLE 1 Most prolific stakeholders of green corridor research.

Factor	Particular	Numbers
Publications by country	China	77
	Spain	44
	India	32
	United Kingdom	22
	United States of America	22
	France	17
	Italy	17
	Brazil	16
	Germany	14
	Canada	12
Publications by affiliations	Chinese Academy of Sciences	24
	Xinjiang Institute of Ecology and Geography Chinese Academy of Sciences	14
	Consejo Superior de Investigaciones Científicas	9
	Universidad de Granada	9
	CSIC - Instituto de Recursos Naturales y Agrobiologia de Sevilla IRNAS	8
	Technical University of Denmark	8
	University of Chinese Academy of Sciences	7
	Tallinna Tehnikaülikool	7
	Universidade de São Paulo	6
	Peking University	6
Publications by funding sponsor	National Natural Science Foundation of China	22
	European Commission	11
	Chinese Academy of Sciences	7
	Conselho Nacional de Desenvolvimento Científico e Tecnológico	5
	Seventh Framework Programme	5
	Coordenação de Aperfeiçoamento de Pessoal de Nível Superior	4
	Junta de Andalucía	4
	Ministerio de Ciencia e Innovación	4
	Agence Nationale de la Recherche	3
	European Regional Development Fund	3
Publications by subject area	Environmental Science	162
	Social Sciences	119
	Engineering	94
	Agricultural and Biological Sciences	90
	Computer Science	59
	Earth and Planetary Sciences	55
	Energy	29
	Business, Management, and Accounting	24
	Decision Sciences	15
	Materials Science	15
	Mathematics	13
	Economics, Econometrics, and Finance	12
	Medicine	11
	Multidisciplinary	10
	Physics and Astronomy	10
	Chemical Engineering	7
	Arts and Humanities	6
	Biochemistry, Genetics, and Molecular Biology	6

(Continued on following page)

TABLE 1 (*Continued*) Most prolific stakeholders of green corridor research.

Factor	Particular	Numbers
	Pharmacology, Toxicology, and Pharmaceutics	6
	Chemistry	5
	Immunology and Microbiology	2
	Health Professions	1
	Nursing	1
	Psychology	1

by-product of development projects; therefore, global development agencies must give it serious consideration.

Technique for analyzing green corridor research

A bibliometric technique is applied in the current study to conduct a review of green corridor research. The present study analyzes the performance and intellectual structure of the existing literature on green corridor that has been published in journals that are indexed in Scopus. In particular, journals that are indexed in Scopus must meet a stringent set of criteria in order to be indexed in Scopus. Scopus is a comprehensive database that contains a large number of journals (Paul et al., 2021). The phrase "green corridor" is used to search as the keyword throughout this research, which allows the bibliometric information and full texts of journal articles to be retrieved from Scopus (a database that serves as both a search mechanism and an acquisition tool), during the period of time up to June 2022.

Following the completion of the search, a total of 406 documents were found. The research relied on the "filtered results" codes (filters) that were given out by Scopus in order to arrange the documents that were returned as a result of the search. This helped the researchers organize and refine the articles. In particular, the codes perform the function of document characteristics that were utilized for the purpose of document purification (or filtering). Publications were either included or omitted from the analysis based on the codes. To be more specific, the review is comprised of "English" (language) "articles" (document types) that were published in "journals" (source type) in subject areas that were thought to be pertinent to green corridor. More importantly, the criteria that were utilized to arrange and purify the search results are similar to the suggestions that were made by Donthu et al. (2021), as well as those made by Paul et al. (2021). After the results of the search were sorted and cleaned up, a total of 406 documents were found to have been returned.

In particular, this perspective is based on the performance analysis that was conducted in order to determine the metrics that characterize the publication and citation patterns, as well as the authors, journals, and documents that are the most prolific in the field of green corridor research. This study also does scientific mapping in the form of bibliographic coupling, which groups documents based on similarities in shared references (Boyack and Klavans, 2010), and co-word analysis, which groups documents based on the co-occurrence of keywords. Both of these methods are described in the following paragraphs (Donthu et al., 2021).

The performance and intellectual structure of green corridor research

The first article with the title "Green corridors: a discussion of a planning idea" in the Scopus database dates back to 1990. From that point forward until June 2022, a total of 406 publications were added to Scopus. Of the total papers, 283 were cited, suggesting that 47.16% of the papers had references. These papers got a total of 4853 citations, for an average of 11.95 citations per document, which is lower than equivalent emerging concepts in the social sciences and management. The papers comprised journal articles, book chapters, conference proceedings, and reviews. There were a total of two review articles, whereas the rest investigations were empirical. Although the first article on green corridors was published in 1990, even though the research interest did not grow until 2000 (7 out of 406 papers), no article was published in 1998. In 2006, a total of 11 articles on green corridors are published, followed by 28 in 2015. By considering the trend of publication, 46 articles are published in 2020, whereas 40 documents were published in 2021. Considering the publication trend, 46 articles were published in 2020, whereas 40 were published in 2021. Only 15 papers were published between January and May of 2022, indicating that the field is on track to match or exceed its output from the previous year. However, the potential of having a big impact in the near future should not be ignored; thus, future research on green corridors should try to provide the field with fresh and creative ideas that might considerably improve its theory and practice immediately. Overall, it is evident that academics and publishers have not paid much attention to the issue of green corridors, particularly over the past decade while the number of yearly publications has expanded.

Next, we carry out the co-word analysis via VOSviewer. Figure 1 displays that there was a total of 3356 keywords, but from these only 179 met the criteria, which resulted in six primary clusters. The minimum number of occurrences required was five.

According to the co-word analysis, *Cluster 1* (*the red cluster*) has been considered the most significant one; it contains a total of 40 keywords and is referred to as agricultural land and ecology. Agricultural land, animal, anthropogenic influence, conservation management, conservation of nature, management of ecosystems, and management of the environment are the primary terms that fall under this cluster. *Cluster 2* (*the green cluster*) is the second-largest cluster after Cluster 1. It has a total of 37 keywords, each of which appears a minimum of five times, and it is known as the climate change and water conservation cluster. The main keywords in this cluster are climate change, disaster, environmental impact, flood, forestry, groundwater, vegetation, water conservation, water supply, and watershed.

Cluster 3 (*the blue cluster*) also consists of 37 keywords and is the term urban design and land use. In general, the keywords included are biodiversity, connectivity, conservation planning, eastern hemisphere, land use, urban design, and urbanization. *Cluster 4* (*the yellow cluster*) is with 33 qualified keywords as per set criteria. This cluster is termed green corridor and transportation and consists of main keywords such as ambulance, benchmarking, carbon, emergency vehicles, freight transport, green transport, motor transportation, planning, transportation routes, and travel time. *Cluster 5* (*the purple cluster*) is with 32 keywords and is termed mining and soil erosion consisting of main keywords as metal, soil, trace elements, mining, waste, and bioremediation.

Next, we conducted a bibliometric coupling of countries using VOSviwer with criteria of at least five documents per country. This emerged in a total of *six clusters*. The *largest cluster* consists of a total of seven nations, which are Australia, France, India, Iran, Israel, and Singapore. Turkey is also included in this group. Next, *Cluster 5* included the countries such as Denmark, Estonia, Germany, the Netherlands, and the United Kingdom. The following step involves the formation of a cluster consisting of four countries: Hungary, Japan, Malaysia, Poland, and Serbia. Both Cluster 4 and Cluster 5 are made up of four and three counties, respectively. Countries such as Canada, China, Sweden, and the United States make up the members of Cluster 4. The countries that make up Cluster 5 include Brazil, Portugal, and Spain. Greece and Italy are the nations that make up Cluster 6.

A critical perspective and future research agenda

The research in the green corridor field is active since 1990 or even before with probably different names such as "sustainable infrastructure," green transport corridors," and "urban green ways," but the research did not garner a good number of citations. The average citations per year as well as average citations per publication are far below average than similar topics evolved in a similar era. The research visibility of this domain needs to enhance by collaboration and encouraging multidisciplinary publications.

In addition, the review studies in this domain are sparse. In nearly three decades, just two Scopus-indexed studies can be retrieved that synthesized green corridor literature. These studies are surprisingly published in or after 2020 and therefore can be considered that such efforts are recently started. In the absence of systematic review, unwinding extant literature and identification of research gaps to provide a call for the future are pending matters in this domain.

China emerged as a top contributor to green corridor research in terms of research output generated through published papers. However, the research in this firm is dominated by developed countries. In the list of top 10 countries by publication, only three (China, India, and Brazil) are developing economies. In the category of developed counties, there is representation from North America (the United States and Canada) and Europe (the United Kingdom, Germany, France, and Italy). Despite this fact, surprisingly, developed countries like Australia, northern European countries, and Singapore are not listed as top contributors to the field research. The work in the Asian and Australian continents needs to be encouraged as this region is affected by the negative impact of climate change and related consequences.

The funding agencies must initiate calls for grant proposals as currently most of the funding is on the national level. The top funding contributor on the topic is the National Natural Science Foundation of China and the European Commission. International corporations such as World Bank and IMF also can encourage funding in this context. In addition, regional bodies in Asia such as Asian Development Bank can encourage work in this part of the world.

When it comes to the subject domain, a heavy volume of literature is published in the field of environmental science followed by the field of social science. In this case, further research on the topic in the field of business management, psychology, computing, information systems, and energy is encouraged. From the perspective of green corridors, it is evident that although research on this topic is slowly expanding, it is unclear why the leading global development agencies have remained silent on this issue (Table 1).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Interplay among institutional actors for sustainable economic development—Role of green policies, ecoprenuership, and green technological innovation

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This study conceptualizes the impact of Green Economy Policies, namely, green fiscal policy, green investment, and green jobs, on sustainable economic development through direct and serially mediated paths. Ecopreneurship and Green Technological Innovation have been perceived/recognized as potential mediators linking green economy policies to sustainable economic development. The conceptual model sheds light on the integrated role of two main actors—the government of the state and its market forces in moving toward the goal of sustainability and gains for all. It represents that incorporating “green” into public policy creates a suitable environment for green entrepreneurs to propose innovative green technologies and sustainability-led business models. Theoretically supported by Institutional theory, this article aims to contribute to sustainability transition research by focusing on the collective role of different institutional forces in achieving economic gains through a sustainability lens.

KEYWORDS

green economy, sustainable development, ecopreneurship, green technological innovation, green policies

1 Introduction

The notion of sustainable development outlooks the merger of economic and environmental policies as the ultimate solution to the ever-increasing environmental degradation and societal injustice due to human activities (Khoshnava et al., 2019; Mensah, 2019). The burgeoning concerns regarding unsustainability have resulted in the development of international policies and standards to mitigate the adverse effects of humans and businesses on the environment (Pfeffer, 2010; Klarin, 2018). To counter these global issues, governments globally have accepted the need for a greener economy to achieve sustainable economic development (Delai and Takahashi, 2011). Sustainable development intents to use natural resources in a controlled and beneficial way to satisfy the needs of the current and succeeding generations (Keeble, 1988). The inception of sustainability is grounded in the notion of the triple bottom line with social, environmental, and economic dimensions. The social aspect of sustainability includes health and safety, equality, and social concerns; the ecological view covers resource conservation, green product development, clean energy, and carbon emission labeling, and the economic dimension includes the development of green businesses to pursue sustained growth (Costanza et al., 2016; Alwakid et al., 2021). As mentioned by Ahmar et al. (2022), it is the need of the hour to shift from conventional energy sources such as fossil fuels to renewable energy technologies (solar system plants) to ensure a clean and low carbon environment along with economic development (Ali et al., 2021). Therefore, economy, environment, and society, the three underpinnings of sustainable development, are the crucial areas for identifying possible shortcomings and developing relevant green policies (Delai and Takahashi, 2011).

Traditional economic models practiced for decades have brought forth an immense increase in social inequalities and environmental degradation focusing merely on a capitalistic perspective, neglecting the social and ecological sides of economies (Khoshnava et al., 2019). Although economic corridors and developmental programs are crucial drivers of stability for states, they also bring concerns about environmental and economic unsustainability because the improper use of resources exhausts the natural environment (Li et al., 2021). For example, economic corridors involve energy projects that require an excessive use of coal and other natural resources resulting in higher levels of carbon emissions, air and water pollution, excessive cutting of trees, and several diseases (Kouser et al., 2020; Munir and Khayyam, 2020). These burning concerns make it necessary to align the notion of sustainability with the old economic practices to achieve economic growth that is harmless to the environment (Khoshnava et al., 2019). Linking economic corridors with green corridors provides opportunities for economies to achieve fiscal stability with sustainability (Al Masri et al., 2019). The evolvement of green corridors is possible by incorporating green into the existing national policy to provide states with opportunity for growth as it enhances societal and environmental welfare and acts as a source of support from the international community (Kasztelan, 2017).

It is evident from the previous literature regarding economic growth and environmental sustainability (Klarin, 2018). Similarly, a report by UNEP (2014a) suggests that green economy policies are essential in achieving sustainability for countries. The green economy not only deals with ecological deficiencies but also seeks economic transformation to provide welfare and justice to society (Söderholm, 2020). The green economy aims to promote policies and practices that help in the consumption and production of eco-friendly goods to improve the environmental condition to provide equitable natural resources for future generations (UNEP, 2011). Implementing green policies encourages the growth of other facilitators and practitioner of sustainability called ecopreneurs (Hörisch, 2016). Ecopreneurs aim to reform the conventional business policies and means of production by inventing eco-friendly technologies and products to reduce the environmental impact, as the notion of green entrepreneurship is based on the philosophy of sustainability (Santini, 2017; Rodríguez et al., 2019).

The discourse suggests that the concept of green economy, green entrepreneurship, and sustainability is interrelated. Therefore, governments should incorporate eco-friendly policies into regulations and encourage investment in green businesses to provide a cleaner and more sustainable future. The institutional theory supports this study to justify the relationship between green economic policies, ecopreneurship, green technological innovations, and sustainability. The institutional theory states the formal and informal institutions: governmental regulations, culture, family, and community (Tolbert et al., 2011; Zhai and Su, 2019). Governments are in the best place to develop and ensure green and socio-economic cultural norms in businesses and society because it is the responsibility of governments to take immediate actions to tackle the issues of poverty, health, unemployment, and inappropriate infrastructures to pursue sustainable development (Moghimi and Alambeigi, 2012; Zhai and Su, 2019). To attain sustainable economic development, the state should support green entrepreneurship through providing incentives and subsidies to socially conscious businesses and by developing policies related to green investment programs, low carbon developmental policies, pollution prevention strategies, no coal policy, etc. (Aparicio et al., 2016; Alwakid et al., 2021). Concerning the institutional theory, the strong support of governmental institutions and well-built green policies advances green entrepreneurship and sustainable technological innovation that could positively affect the triple bottom line framework of sustainability (Ács et al., 2014).

2 Literature review and hypothesis development

2.1 Direct paths and serial mediation

2.1.1 Green economy policies—Sustainable economic development

The green economy refers to the economy that "improves human wellbeing and social equity while significantly reducing environmental risks and ecological scarcities" (UNEP, 2014a).

The green economy acts as a tool to organize the efficient use of resources through several actors, i.e., governments, industrialists or entrepreneurs, and civil society (Mikhno et al., 2021). To shift from conventional to new sustainability-led policies, state institutions should adopt new practices. The transition from a traditional to a green economy demands a series of reforms such as green investments, green procurement, green technological innovations, eco-friendly international trade, green jobs, and skill building to combine ecological and economic systems (Kasztelan, 2017). Public policymakers can ensure the well-organized use of resources and sustainable development by introducing policies that promote green investments in the country (Pavlyk, 2020). Green investments are one of the most important policy areas to ensure environmental protection because the right investment decisions can reshape an economy (Tran et al., 2020). For example, investing in green infrastructure assists in dealing with climatic challenges and provides cost-efficient means to protect natural habitats. Likewise, governments can use a green fiscal policy to ensure a radical transition toward a green economy leading to sustainable development.

Through fiscal policy, the government regulates the economy by deciding ways to collect and spend money (UNEP, 2014b). Policymakers can influence behavioral changes among the masses by managing the income distribution to achieve the desired social objectives as well as to reduce psychosocial risks (Javaid et al., 2016, 2018, 2019; Meirun et al., 2020). Government initiative to create green jobs enhances the quality of life through the fair distribution of wealth (Kasztelan, 2017). Green economy policies can be used to shift the flow of investments toward environment-friendly projects (Schroeder et al., 2019). Green policies such as environmental subsidies, carbon capture and storage, emission trading, pollution discharge fee, etc., help in reducing emissions and conserving energies (Harrison et al., 2016; Li, 2019). Green economy policies lead to sustainable economic development by following two approaches (Yuan and Zhang, 2020). First, by imposing policies such as pollution discharge fees, governments can force polluting industries to adopt environment-friendly production processes to save costs. Second, green policies act as ecological signals for enterprises to improve their environmental performance. For example, environmental subsidy policy would encourage firms to shift to sustainable economic development practices. Providing subsidies to firms producing sustainable products via sustainable means would serve as a competitive advantage increasing the market share (Yuan and Zhang, 2020). Based on the above discourse, green economy policies are essential for achieving sustained economic development.

2.1.2 Green economy policies—Ecopreneurship

Santini (2017) defines eco-entrepreneurship or ecopreneurship as business activities through an environmental viewpoint. Another study suggests that ecopreneurs are those who create or align businesses with sustainability principles (Kirkwood and Walton, 2010; Galkina and Hultman, 2016). Similarly, ecopreneurship refers to a bridge between economic growth and environmental development to achieve long-term benefits and sustainability for society and economies (Isaak, 2016). Ecopreneurship plays a crucial role in achieving a competitive edge for firms and economies, as the concept of the traditional economic model "take, make, and dispose of" endangers the global economic and environmental sustainability (Ghisellini et al., 2016; Geissdoerfer et al., 2017). According to Usman et al. (2020), the board of an organization is responsible for policymaking that defines the strategic and functional directions for a business model. As ecopreneurs operate on the principle of profit with environmental protection, governments can enhance sustainable economic development by encouraging ecopreneurship. A new paradigm shift is needed to overcome these challenges by developing new regulations and business policies to create a circular economy to promote clean production and responsible consumption, and encourage green awareness at all levels of the state (Geissdoerfer et al., 2017).

Previous studies have interchangeably used the notions of green entrepreneurship with sustainable competitive advantage (Rodríguez et al., 2019). Green entrepreneurship comprises three components, i.e., eco-commitment, eco-innovation, and eco-opportunity (Holger, 2006). The literature suggested that government green policies and regulations, venture investors, corporate social responsibility, and community have a dominant role in encouraging ecopreneurs. Incentivizing ecopreneurs helps promote sustainable business models that lead to sustainable economic development,. for example, to provide subsidies to green-oriented firms (Domańska et al., 2018). By setting pollution control, sustainable technology standards, environmental taxes, renewable energy projects, and waste management targes the governments to ensure eco-friendly ways of doing business (Moghimi and Alambeigi, 2012). Such measures lead to gradual but continuous greening of the organizations that ultimately promote sustainable economic development (Rodríguez et al., 2019).

2.1.3 Ecopreneurship—Green technological innovation

Ecopreneurial businesses aim to achieve environment-friendly economic growth and use innovation to develop sustainable methods for business (Rodríguez-García et al., 2019). Ecopreneurship and green innovation are linked to one another concerning sustainable development. Ecopreneurs value the idea of environmental protection and preservation along with the objective of wealth generation (Rekik and Bergeron, 2017). Previously, government institutions controlled the use of natural resources, but now private institutions and business associations appeared as the key handler of these resources. The capitalist business mindset negatively impacts natural habitats in the form of pollution, global warming, drastic climate change, droughts,

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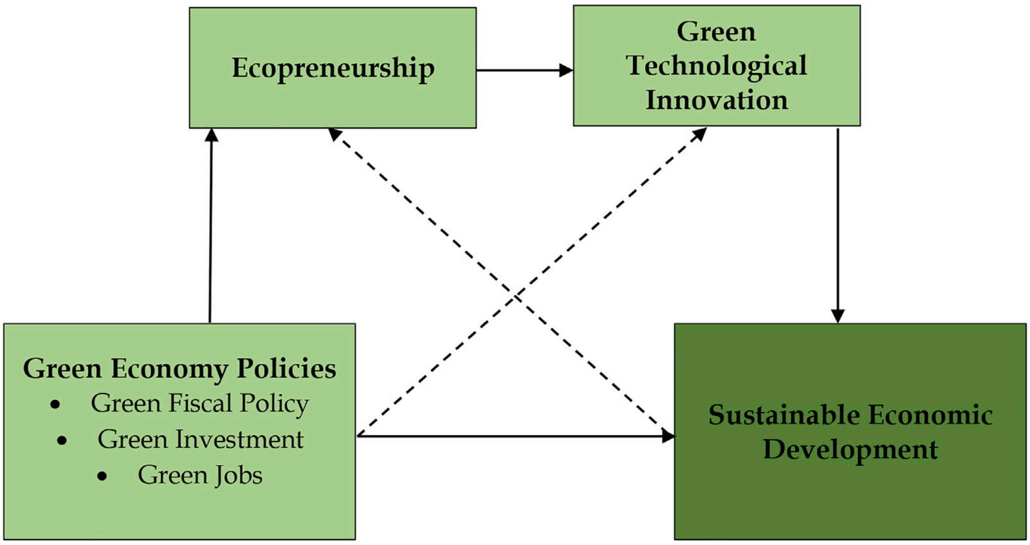

FIGURE 1
Conceptual framework.

severe weather conditions, and forest fires (Domańska et al., 2018). However, contrary to profit-driven businesses, eco-friendly businesses search for potential market opportunities to assist in environmental protection and sustainability (Scales, 2017).

In the search for a sustainable-driven business model, ecopreneurs innovate green technologies to reduce the impact of production processes on the planet and conserve natural resources (Moşteanu et al., 2020). For example, to control and monitor diffuse emissions, technological innovation in tracing and tracking materials is used (Söderholm, 2020). Ecopreneurs treat "innovation in general" and "green innovation" as the same because they consider firms' carbon footprints in almost every operation (Alwakid et al., 2021). In addition to sustainable business models, ecopreneurs adopt green innovations commercially as well. For example, in response to increasing flood risks, financial institutions innovated relative financial instruments, e.g., weather derivatives, catastrophe bonds, etc. (Söderholm, 2020). Also, sustainability-led innovations, either product or process, provide new growth opportunities, cost reduction, build corporate image, and shape consumer preferences in the long run (Rodríguez-García et al., 2019). Hence, ecopreneurship leads to green technological innovations given its commercial and environmental logic.

2.1.4 Green technological innovation—Sustainable economic development

Nations need to adopt green technological innovations to protect the environment from potential harm caused by natural resource depletion. Green technologies improve societal and environmental well-being by reducing industries "ecological footprint" (Mantaeva et al., 2021). Green technologies enable businesses to achieve economic objectives but not at the expense of natural resources. For example, green energy technology produces energy through renewable energy sources, protecting the environment from pollution caused by fossil fuels (Wu et al., 2022). Hence, non-polluting energy production leads to environment-friendly or sustainable economic development. Technological know-how is fundamental to ensure the feasible usage of natural resources to protect the environment from the negative impact of energy imbalances leading to sustainable development (Guo et al., 2020). The technological innovation of recycling plastic in the absence of oxygen comes with immense economic and environmental benefits (Samadhiya et al., 2022). Green technologies ensure less damage to the ecosystem to protect it for future generations. Therefore, such inventions should be promoted at national and international levels. Ecopreneurship and green technological innovation serially mediate the relationship between green economy policies and sustainable economic development shown in the conceptual framework in Figure 1.

2.2 Indirect paths

2.2.1 Ecopreneurship—Sustainable economic development

Presently, the issue of environmental unsustainability has affected all aspects of businesses and human lives in both

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developed and developing nations, which results in the evolution of the green economy notion (Purvis et al., 2019; Yusliza et al., 2020). Sustainable development aims to protect the environment and safeguard the rights of succeeding generations so they can fulfill their needs from natural resources (Keeble, 1988). Economies and businesses are now shifting from traditional capitalistic mindsets to eco-friendly practices encouraging the establishment of green markets and promoting green entrepreneurship globally (Lotfi et al., 2018). Similarly, consumer preferences have shifted toward environment-friendly products, as humans are now more aware of their impact on the environment (Arora, 2018). To change such old practices, ecopreneurs can produce, operate, and innovate new products and bring a green technological change to associate the firm's monetary benefits with sustainability (Sharma and Kushwaha, 2015). The literature posited ecopreneurship as a facilitator of sustainable economic development (Hörisch, 2016). Because it plays an eminent role in achieving competitiveness, economic growth creates sustainable jobs, promotes accountability, and deals with the issue of environmental pollution and can enable firms to reduce their carbon footprints (İyigün, 2015). Sustainable entrepreneurship paves the way for green corridors by providing a green business framework and green innovations for the wellness of the ecosystem (Prause and Hunke, 2014).

2.2.2 Green economy policies—Green technological innovation

United Nations Sustainable Development Goals (SDGs) aimed at establishing coherence between the world economic system and the ecological system requiring the adoption of a green economy. The ultimate goal of achieving economic prosperity without sidelining the environment requires green policies for sustainable production and consumption patterns (Söderholm, 2020). Government policies significantly contribute to sustainable technological innovations that address climatic challenges with economic challenges (D'Amato et al., 2021). Sustainable technological innovations face many challenges like high costs, lack of funds, skilled labor, etc. (Söderholm, 2020). However, green policies by the government, i.e., green investment and green jobs and skills training, may overcome the hindrances. By providing support through green investments such as offering financial and tax incentives to enterprises, governments enable and promote private firms to innovate sustainable technologies, e.g., carbon neutral products (Wu et al., 2022).

Besides providing the legal framework regarding the licensing procedures, regulation of emissions via taxes, etc., states also work in partnership with the private sector to provide a mix of different policy instruments for sustainable technology innovation (Tran et al., 2020). For example, in the case of waste management, mixing the taxation policy with a recycling subsidy would lessen the number of waste materials as the industries would prefer recycled materials over raw materials (Calcott and Walls, 2005). Furthermore, green policies at the state level increase the demand for sustainable technological innovation through awareness campaigns among the public about green consumption and its positive effects on the environment (Musango et al., 2014). Hence, it is proposed that green economy policies would promote technological innovations to achieve economic gains along with environmental protection.

3 Discussion

This article used institutional theory to highlight the impact of state institutions on sustainable economic development in the light of green economy policies. It also discusses the indirect effect of green economy policies on sustainable economic development via ecopreneurship and green technological innovation, as shown in Figure 1.

3.1 Theoretical and practical contributions

Despite the burgeoning debates on sustainable development and environmental protection, developing economies, in particular, lack green policy frameworks. One of the key reasons is the lack of political will to consider the severity of environmental concerns (Khan et al., 2019). Another possible reason is the little authority given to the local tier of government that is majorly responsible for policy implementation (Dupont and Oberthür, 2012). Therefore, the objective of this article was to highlight the role of green economy policies in promoting the notion of "green" in business models and technological advancements to ensure sustainability-led economic development. Green initiatives by the government in the form of green policies support ecopreneurs that result in sustainable business models based on green technologies. Hence, the collective effort of state and market forces could result in economic development safe for the environment. This conceptual article aims to clarify that the constitution of environment-friendly policies will positively impact green entrepreneurship and sustainability. Due to the increased attention of government, policymakers, businesses, and societies toward environmental protection, the need for sustainable policies and ecopreneurs has increased for the protection of natural resources. To ensure the implementation of green policies, developing economies require the adoption of cross-sector and multi-level integration that involves addressing environmental issues at all three tiers of government: federal, state/provincial, and local authorities (Aall et al., 2015). The effective enforcement of green policies at all three government tiers requires two steps. First, the government signals specific environmental concerns to the federal and provincial ministries, and second, the ministries issue policy signals for dealing with the specific environmental issue to the local authorities. This study also responds to the questions raised by Galkina and Hultman

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(2016) regarding the driving force behind ecopreneurship. Green regulatory policies serve as the driving force behind green entrepreneurship. Governments should devise and communicate a clear pollution discharge fee policy. The charges based on the number of pollutants discharged would force the emitters to reduce the social cost. Hence, adopting green policies is essential for sustainable economic development (Bitat, 2018; Shi et al., 2019) Additionally, governments need to implement energy efficiency policies to reduce the impact of emissions on the environment. According to Li et al. (2022), high energy consumption leads to increased carbon dioxide (CO_2) emissions and environmental degradation. In the emission trading system, a government decides the maximum emissions allowed to manufacturing firms and provides permits for per-unit emissions (Lyu et al., 2020). In the case of relatively high price for allowances, firms may consider adopting sustainably led business practices as a cheaper option. Moreover, policies such as green fiscal reforms, linking government expenditures with environmental goals, green funding to projects or businesses using renewable energy and sustainable production methods, and green jobs act as driving forces for ecopreneurs. According to Alwakid et al. (2021), the idea of ecopreneurship is in its developmental stage and requires more focus from researchers, practitioners, and policymakers. Additionally, educational institutions should also teach the concept of sustainability to produce more and more ecopreneurs in the generations to come (Gao et al., 2019).

4 Conclusion

The objective of this article was to highlight and integrate the role of different institutional actors in achieving the goal of environmental and economic development. The first part discussed the importance and impact of green economy policies on sustainable economic development. The second part covered the mediation path of ecopreneurship and green technological innovation in green economy policy—sustainable economic development relationship. Hence, the conceptual model sheds light on the integrated role of two main actors, government of the state and its market forces in moving toward the goal of sustainability and gains for all. Several policy suggestions are proposed in the study. States should provide policy support to the firms using sustainable means of production. Emission trading policy should be implemented to reduce CO_2 and other hazardous emissions. Policies such as environmental subsidies should be used to encourage ecopreneurs and green technological innovations. Innovations such as low-carbon technologies require policy support in the form of government fundings. Therefore, in combination with policy instruments, financial support should be given to sustainability-led firms in the form of reduced taxes. In compliance with the institutional theory, green economy policies aimed at introducing and improving sustainable business practices promote ecopreneurship and green technological innovation and improve institutional quality, ultimately leading to sustainable economic development. However, in future, we need empirical work in the form of real-life case studies or national-level research for understanding the complex processes through which green policies advance ecopreneurship and to identify the hindrances in achieving sustainable economic development through the proposed path.

Author contributions

XW, SB, MUJ, HY, and AJ conceptualizes the manuscript. XW, HY, and AAS proof read and helped in revisions.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Spatial Spillover Effects Promote the Overall Improvement of Urban Competitiveness: Evidence of SDM in Asian Cities

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The competitiveness of a city is in the process of competitive development. This study uses the Spatial Dubin Model (SDM) technique to explore the influencing factors and spatial spillover effects of the economic competitiveness of 565 cities in Asia. The study finds that the factor spillover bandwidth affecting the improvement of urban competitiveness is primarily concentrated in the range of 1,000 km. Furthermore, with a maximum elasticity value of roughly 11.6%, a city's spatial spillover effect is a crucial factor in selecting strategies for enhancing its competitiveness level. Financial services, industrial structure, and human resources all have an influence on the level of urban competitiveness. Therefore, in order to better improve the level of regional urban competitiveness, one is to improve the overall level of factors affecting urban competitiveness and enhance the competitiveness of the city itself; the other is to enhance the flow of factors between regions and make full use of the space of factors Spillover effects enhance the level of regional competitiveness; the third is to enhance the spatial interaction between regions and use the externality of urban competitiveness to achieve an overall improvement in the level of regional competitiveness.

Keywords: urban competitiveness, spatial spillover, spillover bandwidth, SDM, Asia

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INTRODUCTION

In the 21st century, with the acceleration of globalization and the rapid development of informatization, the status of cities in global development has become increasingly prominent, and competition among cities in terms of factors and industries has become increasingly fierce. According to the World Urban Outlook (Revision 2018) report of Economic and Social Affairs of the United Nations Secretariat, as the global economic recovery and urbanization process accelerate, 68% of the population is expected to live in cities by 2050 worldwide, and China's urban population will grow by 255 million. Cities will become the primary living area of human beings, and the competition between cities will gradually depend on the competitiveness levels of cities (Begg, 1999). Therefore, urban competitiveness research has become a hot topic in the fields of economics, urban planning and management, and an increasing number of academic institutions and scholars have joined the ranks of urban competitiveness research. The extent to which a city, or urban region, in reference to other "contending" cities, is able to provide the employment, income, sports and recreational amenities, degree of social coherence, governance, and urban environment to which its current and potential new residents strive (GUCP and competitiveness, 2020). What is the significance of evaluating urban (and, by extension, regional and national) competitiveness? The answer is that competitiveness cannot be improved until it can be quantified. Because cities compete on a regional, national, and global scale, increasing urban competitiveness enhances city productivity, visibility, popularity, attractiveness, and quality of life, as well as regional and national ones (Bruneckiene et al., 2010). It is clear that understanding and identifying the key factors affecting urban competitiveness, combining their comparative advantages and improving the level of comprehensive competitiveness of cities have become urgent tasks for urban development. Urban competitiveness may indicate the degree of urban development and comprehensive strength, which dictate the trajectory of urban growth (Song and Xie, 2021). The study of urban competitiveness may assist the government in strengthening its position and clarifying its direction, allowing it to better understand the genuine situation in each city and design more appropriate programmes. Different cities' growth plans are now distinct (Cui and Xu, 2021).

The essence of urban competitiveness is the ability to create more value and welfare for the city (Lever and Turok, 1999; Budd and Hirmis, 2004). At the heart of city competition is the search for different ways and means to create, attract, sustain, and use diverse resources, knowledge, ideas, and innovations to support each individual city's economic growth and, as a result, to strengthen the city's position in the urban hierarchy both short-term and long-term (Činčikaitė and Meidute-Kavaliauskiene, 2021). The existing research has primarily focused on qualitative analyses of the factors affecting competitiveness. For example, the basic driving forces of urban development include scientific and technological progress, financial capital, ecological environment, culture and the institutional environment were ignored. In recent years, with the promotion of information and technology in urban development, the role of information and technology in cities has risen rapidly, and science and technology innovation centers and central cities of emerging economies are entering the ranks of the most competitive cities (Ni, 2001) (Song and Xie, 2019). Limited by the availability of urban data, there are relatively few quantitative studies on the degree of influence of the above factors on urban competitiveness. There are also few studies on the key elements of urban competitiveness and the spatial spillover effect. There are several ideas that attempt to explain what it takes for cities to be competitive.

The first is the trade base theory of urban competitiveness, which asserts that exports play a key role in defining a city's competitiveness (Rowthorn, 1999). The second approach to urban competitiveness is the city's growing returns approach, in which municipal competitiveness and economic success are dependent on the capacity to recruit talented and educated labor, money, and technology (Hoover; 1937, 1948). The third endogenous growth model considers the city to be a knowledge and innovation center. Lucas (2001) and Romer (1990) emphasize the significance of education, learning by doing, and knowledge spillover. Schumpeter (1934) emphasizes the need of profit-making research and development by firms. The fourth is cluster theory is of urban competitiveness. Spatial/geographical proximity is important for positive and mutually reinforcing interactions that result in competitive advantage and innovation among businesses (Porter, 1990; Porter, 1998; Martin and Simmie, 2008). Fifth, there is a cultural model of economic competitiveness in cities; social and cultural systems either encourage or impede city's growth and development (Martin and Simmie, 2008).

Because of their relative relevance in the process of urban competitiveness, this study utilizes a mix of these theoretical models. In view of this trend, this paper uses the latest spatial econometrics method, the generalized nested space (GNS) model, and economic competitiveness data for 565 sample cities in Asia to analyze their urban competitiveness level. By controlling the spatial autocorrelation of explanatory variables, the impacts of key elements on urban competitiveness are quantitatively analyzed, and the spatial spillover effect is measured. On this basis, relevant policy implications are discussed, and targeted policy recommendations are provided for enhancing urban competitiveness and building urban agglomerations and economic belts. This study takes into consideration previously disregarded scientific and technical factors, making it more measurable.

The following is how the rest of this article is organized: The second section is a brief review of important literature in this area. The third section describes how to create an empirical analysis model and analyze data. The fourth section looks at results for measurement models, along with optimal model selection and robustness test. The fifth section discusses the mechanisms of spatial spillover effect and urban competitiveness. The key findings of the study are discussed in the sixth section.

LITERATURE REVIEW

tSince the concept of urban competitiveness was first proposed, it has received extensive attention from scholars worldwide. The existing literature shows that factors such as the business environment, cultural foundation, infrastructure, technological innovation, and industry type will have an important impact on the competitiveness of cities, countries and regions (Lacka, 2015; Mullen and Marsden, 2015; Krammer, 2017; Chen et al., 2017; Garden and marten, 2005). Moreover, Stefan (2014) study shows that not single, but multiple factors influence the level of urban competitiveness, such as the business environment, infrastructure, human resources, cultural resources, natural resources, and specific regulatory frameworks, namely, the institutional environment. There is a strong correlation between the level of competitiveness of a city and its institutional environment. Factors such as talent, government management, capital, technology and infrastructure have been the main drivers of urban competitiveness of smart cities (Matos et al., 2017; Sycheva et al., 2020). As the flow of factors between cities continues to accelerate, the above mentioned literature has to a certain extent discussed the important factors affecting the level of urban competitiveness but neglected the impact of spatial spillover between cities on the level of urban competitiveness.

With the rapid development of spatial economics and econometrics, the spatial spillover effect of factors between regions has gradually become accepted. In the existing literature, some scholars have explored the spatial spillover of factors between cities, which plays an important role in promoting urban competitiveness. Cohen and Morrison Paul, (2004), Bronzini and Piselli, (2009), Hu and Li (2015), Wang and Ni (2016) and other scholars have shown that infrastructure such as transportation has a spatial spillover effect on regional economic growth and total factor productivity, thus affecting the competitiveness in a region (Gunderson et al., 2017). Fischer et al. (2009) studied the European region and argued that the spatial autocorrelation and spatial spillover of knowledge between regions will affect the competitiveness level of the region through productivity levels; this effect increases with decreasing distance) Capone and Boix (2005) used a nonspatial model and a spatial model to examine concerning several types of Italian tourism local systems (rural systems, artistic cities, tourist districts) in order to assess external economics and territorial networks. In conclusion, higher growth rates are related with the existence of all stages of the tourism filiere in the local network. Unlike infrastructure spillover and knowledge spillover, Wang (2013) used a nonspatial model and a spatial Durbin model to examine the impact of environmental regulation on industrial competitiveness. According to this study, environmental regulation has a significant geographical spillover impact. Foreign direct investment, the number of scientific and technical personnel, and the industrial scale related to environmental regulation all have a significant positive spillover effect on industrial competitiveness. They stimulate regional competition and improves a region's overall competitiveness. Su et al. (2021) studied the regional spillovers between digital financial technology and urban ecological efficiency using data from 284 Chinese cities from 2008 to 2018. Financial technology and urban ecological efficiency complement one another, with the latter taking precedence. Spatial and temporal heterogeneity characterizes the spatial interaction spillover effect between the two. These findings contribute to the discovery of new regional ecological efficiency drivers and to the development of digital finance and green ecology in tandem.

In contrast to the above studies, the main research object of this paper is the internal region of a country. Some scholars have extended the research object of urban competitiveness to the country level. Luh et al. (2016) studied the impact of trade-related spillover on the industrial competitiveness of China and the Organization for Economic Cooperation and Development (OECD). The authors suggested that trade-related spillovers can both positively and negatively impact the industrial competitiveness of OECD countries. Both trade and trade-related logistics also have an impact on urban competitiveness. Taking the countries along the "New Silk Road Economic Belt" as the research object, Liu et al. (2017) applied dynamic analysis methods and found that the spatial spillover effect of logistical competitiveness plays an important role in improving urban competitiveness. It is clear that the spatial spillover effect between cities or countries is an important factor for enhancing competitiveness.

Hashi and Stojčić (2013) explored how knowledge spillovers created by firms' innovation efforts influence their industries' capacity to compete on quality. The study's findings confirm the link between innovation, quality improvement, and industry market share, and point to numerous forms of spillover that are important for the competitiveness of national industries in EU member states.

The spatial spillover effect between cities can vary, and this effect is largely limited by geospatial distance. In the existing literature, scholars generally suggest that the overflow-concentration area of the factor spatial spillover effect is between 200 and 1,000 km, and the overflow margin of the spatial spillover effect is as great as 3,000 km. For example, Rodríguez-Pose and Crescenzi (2008) proposed the optimal distance for space overflow as 3 h of travel time (approximately 200 km), which is consistent with the conclusion of Yu et al. (2016) regarding the attenuation of agglomeration space in the productive service industry. Taking China as the research object, Wenqing (2013) reported that the spatial spillover of market potential has the greatest impact on the economy for regions within 1,000 km of the provincial capital. When this distance exceeds 3,000 km, the spatial spillover effect is weakened. Gong and Xu, (2017) suggested a high elasticity distance of 1,150 km~1,650 km for the spatial spillover effect of regional utilization capacity and an effective spillover boundary of 2,450 km. Chiu and Liu (2021) studied urban development and competitiveness in Keelung, a secondary region city. The study reviewed various urban competitiveness assessment methods and indices used in Taiwan and worldwide. Then, a system for measuring urban competitiveness was developed to identify indices of urban growth. The assessment indices were built using FDM and DANP, with expert opinion determining the effects of different dimensions on each other. Using the DEMATEL-based ANP, experts deemed governance, economics, and society dimensions critical to city competitiveness. Xu and Cui (2021), b y looking at data on urban growth from 2010 to 2018, found 16 indicators of urban competitiveness, such as urban GDP and per capita green space area. They then used principal component analysis to figure out which cities were the most competitive in recent years. In addition, the analytic hierarchy method showed that the main factors that make a city competitive are its size and its ability to compete with other cities in the environment. The report looks at how each city is growing and comes up with Shandong Peninsula Blue Economic Zone development countermeasures.

Although many scholars have studied urban competitiveness (Jiang and Shen, 2010; Lember et al., 2011; Ni et al., 2014), existing research still has the three following research gaps. First, the existing research on the factors affecting urban competitiveness is relatively scattered (Ni et al., 2014; Ni and Jie, 2014). Basically, studies on competitiveness have focused on a single dimension. It is difficult to identify which factors simultaneously affect urban competitiveness, and targeted discussions on the improvement of urban competitiveness are rare. Second, the spatial spillover effect is generally studied between cities (Jiang andShen, 2010; Shen and Yang, 2014). Unfortunately, the spatial spillover effects of different factors affecting urban competitiveness have not attracted sufficient attention. Third, the existing literature on urban competitiveness primarily focuses on qualitatively determining which factors affect urban competitiveness, while there are relatively few quantitative studies on urban competitiveness. In view of these shortcomings, this study uses the spatial econometrics method to quantitatively analyze the various factors affecting urban competitiveness and spatial spillover effects. The spillover boundary, within which urban competitiveness is enhanced, is employed to provide targeted policy recommendations for improving urban competitiveness.

MODEL CONSTRUCTION AND INDEX SELECTION

Construction of an Empirical Analysis Model

Elhorst (2014) and Halleck Vega and Elhorst (2015) looked at eight different types of measurement models, including the benchmark OLS model used in the generalized nested space (GNS) model. When certain conditions are met, the GNS model can be gradually reduced to the OLS baseline model, as shown in **Figure 1**. The GNS can be expressed as:

$$Y = \rho WY + \alpha \iota_N + X\beta + WX\theta + u, \quad u = \lambda Wu + \varepsilon \qquad (1)$$

where Y is an explanatory variable, W is a spatial weight matrix, ι_N is a constant, X is an explanatory variable matrix, u is an error term, and ρ, α, β, θ and λ are parameters to be estimated. When the above five parameters are equal to zero, the GNS is simplified to OLS. These simplification conditions can be found in the report of Elhorst (2014). When modeling specificity, Halleck Vega and Elhorst (2015) suggested setting the model to the GNS form and then selecting the optimal empirical analysis model based on a parameter test. Thus, this paper will establish the following GNS model for an empirical analysis of global urban competitiveness including spatial factors:

$$competitivness = p \times W \times competitivness + \alpha tN + X\beta + WX\theta + \mu \qquad (2)$$

where $\mu = \lambda W\mu + \varepsilon$

$$X = \left(finance, fina_{squ}, tech, indust, psacp, demand, business, \text{inf}rastru, live\right)$$

In **Equation 2**, *competitivness* is the explanatory variable, that is, the economic competitiveness level of the city, ι_N is a constant, W is a spatial weight matrix, X is an explanatory variable matrix which includes city's financial services, square term of the financial services, city's technological innovation capability, city's industrial system, city's human capital, u is an error term, urban demand, city's business cost, infrastructure index, living environment indicator and ρ, α, β, θ and λ are parameters to be estimated by the model.

Variable Selection

The explanatory variable of this paper is the level of urban competitiveness. The level of urban competitiveness is the ability of a city to create value and continue to create value in the future. In the short term, this factor represents the scale, speed and efficiency of current value creation. Therefore, the level of urban competitiveness is determined following the method of Peng et al. (2017), based on the economic growth of the city and its comprehensive economic efficiency.

The conditions for promoting urban competitiveness are based on the urban environment, including the soft environment and hard environment. Through the spatial agglomeration of economic entities such as talent and enterprises, the absolute and comparative advantages of the urban industrial system and the competitiveness of the city are determined. Following Peng et al. (2017), this paper selects nine explanatory variables to explore the competitiveness of Asian cities. The first variable is the financial service level of the city (finance), which reflects the city's ability to mobilize savings and absorb and allocate capital; this factor is based on the bank index and the number of bank branches, and its inverse U-shaped relationship with the level of competitiveness is examined. The second variable is the city's technological innovation capability (tech), which is the fundamental determinant of new global cities and is determined by the city's patent index and paper index. The third variable is the city's industrial system (indust), which is used to reflect the city's industrial quality and modernization level, specifically based on the number of urban production services and the number of technology companies. The fourth variable is the city's human capital (psacp), which is the population of the city that can create wealth and value, determined from the size of the labor force, the proportion of inhabitants aged 20–29 years and the university index. The fifth variable is the urban demand (demand) measured by the disposable income of urban residents. The sixth variable is the city's business cost (business), which is based on the ratio of loan interest rates, tax to GDP, and per capita disposable income to the benchmark hotel price, reflecting the level of corporate income within the city. The seventh variable is the infrastructure index (infrastru), which reflects the basic conditions of the city, based on the city's shipping convenience, broadband users and aviation convenience. The eighth factor is the living environment indicator (live), reflecting urban life and safety and determined from the city's PM2.5 and crime rate. It should be noted that this paper takes a square term (fina_squ) for the city's financial services, reflecting the need for a city's financial services to develop to a certain extent in order to effectively promote the city's competitiveness.

To assess the level of urban economic competitiveness and its subindicators, we first conduct a dimensionless indexing process for each specific indicator dataset, and equal weights are added to form a comprehensive index. The formula is

$$X_{ik} = \sum\nolimits_{jk=0}^{n}\left(\frac{x_{ijk} - x\bar{x}_{jk}}{\theta^2}\right)$$

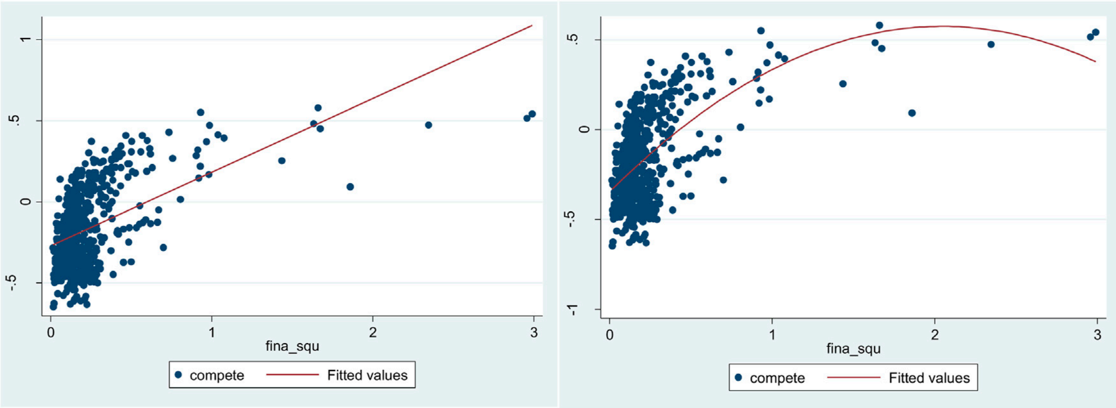

FIGURE 1 | Fitting Chart for Performance in Financial Services and Urban Competitiveness.

X_{ik} represents a composite variable, where k is the number of a specific composite variable. x_{ijk} represents a specific indicator value that constitutes a composite variable, $x\bar{x}_{jk}$ represents the mean of the indicator values for all sample cities that constitute a specific indicator of the composite variable, θ^2 is the variance, and j is equal to 0, 1, 2, n.

Data-Processing Methods

First, all of the indexes are treated as dimensionless. The dimensions of each global city competitiveness indicator differ, and all of the indicator data must be dimensionless. This report primarily adopts four methods: standardization, indexing, the threshold method and the percentage level method.

The standardized calculation formula is $X_i = \frac{(x_i - \bar{x})}{Q^2}$, where X_i is the value after x_i is converted, x_i is the original value, $\bar{x}$ is the average value, Q^2 is the variance, and X_i is the normalized value.

The calculation formula for the exponential method is $X_i = \frac{x_i}{x_{oi}}$, where X_i is the value after x_i is converted, x_i is the original value, x_{oi} is the maximum value, and X_i is the index.

The calculation formula for the threshold method is $X_i = \frac{(x_i - x_{Min})}{(x_{Max} - x_{Min})}$, where X_i is the value after x_i is converted, x_i is the original value, x_{Max} is the maximum sample value, and x_{Min} is the minimum sample value.

The calculation formula for the percentage level method is $X_i = \frac{n_i}{(n_i - N_i)}$, where X_i is the value after x_i is converted, x_i is the original value, n_i is the number of samples with values smaller than x_i, and N_i is the number of samples with values greater than or equal to x_i, excluding x_i.

Next, we calculate the sub competitiveness index. All indexes that have undergone dimensionless treatment are treated by an equal weight addition, and the indexes of competitiveness for each subitem are obtained. The formula is

$$z_{il} = \sum_j z_{ilj}$$

where z_{il} indicates the competitiveness of each subitem, and z_{ilj} indicates the indicators included in the sub competitiveness.

We then calculate the comprehensive score of global city competitiveness, resulting in the score data for this article.

The research object in this paper includes 565 cities in Asia with more than 500,000 people. The main data sources are the database of the Center for Urban and Competitive Research of the Chinese Academy of Social Sciences and cross-sectional data from the International Statistical Yearbook 2016.

EMPIRICAL ANALYSIS AND MODEL ROBUSTNESS TEST

Comparison of Estimation Results for Eight Types of Measurement Models and Optimal Model Selection

Halleck Vega and Elhorst (2015) gave a relationship among eight models, including the baseline model OLS and seven spatial econometric models, and suggested that eight different econometric models could be simultaneously estimated in an empirical analysis. The optimal measurement model can then be selected based on the test parameters of the model estimation results. Following this approach, **Table 1** shows the estimation results for eight types of measurement models, including the baseline model OLS.

By comparing the results for the reference model OLS and the seven spatial measurement models, the SDM estimation results R^2 and $adj - R^2$ are 0.83 and 0.826, respectively, which are the largest values among all of the models; the error square sum σ^2 is 0.009, which is the smallest among all of the models; and the log-likelihood value is 495.42, which is the largest among all of the models; thus, the SDM for a space-time double fixed effect is the optimal estimation model. Moreover, the LM test rejects SAR and SEM as optimal estimation models at the 1% significance level. Although the SDM for a dual fixed effects of time and space is the optimal measurement model; however, the parameter estimation results given by the different models are highly consistent.

According to the estimation results of the SDM, the quadratic term of the financial service, technological innovation capability,

TABLE 1 | Comparison of 8 types of measurement models and the selection of an optimal model.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	**SAR**	**SEM**	**SLX**	**SDM**	**SDEM**	**SARAR**	**GNS**
Interpret	−0.48*** (−8.4)	−0.03*** (−4.6)	−0.47*** (−7.5)	−0.50*** (−4.6)	−0.32*** (−3.1)	−0.38*** (−3.2)	−0.47*** (−6.7)	−0.38*** (−3.1)
Finance	−0.12*** (−3.8)	−0.08*** (−2.6)	0.003 (0.10)	−0.03 (−0.8)	0.020 (0.56)	0007 (0.20)	0.004 (0.10)	0.008 (0.21)
finc_squ	0.094*** (3.23)	0.096*** (3.40)	0.057** (2.12)	0.073*** (2.53)	0.061** (2.22)	0.063** (2.25)	0.057** (2.10)	0.060** (2.14)
Tech	0.005*** (3.17)	0.005*** (2.98)	0.002* (1.69)	0.002* (1.75)	0.002* (1.83)	0.002* (1.73)	0.002 (1.46)	0.002* (1.71)
Indust	0.007*** (3.17)	0.006*** (2.82)	0.004* (1.89)	0.004* (1.91)	0.003* (1.84)	0.003* (1.93)	0.004* (1.89)	0.003 (1.35)
Psacp	0.034*** (2.51)	0.044*** (3.26)	0.017 (1.64)	0.011* (1.71)	0.112* (1.84)	0.012* (1.89)	0.017* (1.73)	0.013* (1.94)
Demand	0.309*** (11.3)	0.290*** (10.8)	0.252*** (9.87)	0.308*** (10.9)	0.269*** (10.1)	0.273*** (9.86)	0.252*** (9.65)	0.273*** (9.63)
Business	0.354*** (7.20)	0.307*** (6.25)	0.381*** (7.81)	0.374*** (7.12)	0.375*** (7.59)	0.363*** (7.28)	0.381*** (7.78)	0.358*** (7.13)
Institute	0.071** (2.16)	0.057* (1.77)	0.072** (2.11)	0.094*** (2.59)	0.073** (2.13)	0.081** (2.38)	0.072** (2.11)	0.083 (2.45)
Infrastru	0.537*** (9.64)	0.403*** (6.47)	0.529*** (7.99)	0.488*** (6.27)	0.468*** (6.41)	0.484*** (6.59)	0.529*** (7.49)	0.484*** (6.61)
livelihood	0.110*** (3.29)	0.079*** (2.37)	0.108*** (3.19)	0.087** (2.40)	0.096*** (2.81)	0.089*** (2.62)	0.107*** (3.17)	0.085*** (2.50)
W×finance	—	—	—	−0.39*** (−4.8)	−0.25*** (−3.2)	−0.26** (−2.2)	—	−0.21* (−1.7)
W×finc_squ	—	—	—	0.290** (2.06)	0.097 (0.72)	0.094 (0.473)	—	0.064 (0.31)
W×tech	—	—	—	0.010** (2.24)	0.002 (0.39)	0.015** (2.02)	—	0.018** (1.96)
W×indust	—	—	—	0.011 (0.94)	−0.01 (−0.5)	−0.01 (−0.5)	—	−0.01 (−0.6)
W×psacp	—	—	—	0.107*** (2.58)	0.064* (1.71)	0.128* (1.85)	—	0.145* (1.83)
W×demand	—	—	—	0.052 (1.05)	−0.08 (−1.5)	0.099* (1.65)	—	0.126 (1.18)
W×business	—	—	—	−0.11 (−0.7)	−0.34** (−2.4)	−0.25 (−1.1)	—	−0.18 (−0.7)
W×institute	—	—	—	−0.03 (−0.4)	0.079 (0.99)	0.123 (1.08)	—	0.121 (1.01)
W×infrastru	—	—	—	−014 (−1.1)	−0.28** (−2.2)	−0.09 (−0.5)	—	−0.06 (−0.3)
W×livelihood	—	—	—	0.071 (0.81)	−0.12 (−1.4)	−0.07 (−0.5)	—	−0.05 (−0.3)
ρ	—	0.225*** (4.57)	—	—	0.384*** (6.68)	—	−0.01 (−0.1)	−0.15 (−0.5)
λ	—	—	0.719*** (10.0)	—	—	0.714*** (9.90)	0.720*** (9.38)	0.783*** (8.01)
R^2	0.801	0.807	0.829	0.817	0.833	0.8261	0.820	0.827
$adj-R^2$	0.797	0.804	0.826	0.811	0.826	0.820	0.816	0.821
D-W	1.849	—	—	1.901	—	—	—	—
σ^2	0.012	0.012	0.010	0.012	0.009	0.010	0.011	0.010
log-like	161.942	453.80	481.63		495.42	492.95	481.63	493.102
LM test SAR	18.56*** [0.000]	—	—	—	—	—	—	—
Ro-LM SAR	0.075 [0.783]	—	—	—	—	—	—	—
LM test SEM	217.0*** [0.000]	—	—	—	—	—	—	—
ro-LM SEM	198.5 [0.000]	—	—	—	—	—	—	—

*Note. ***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively; t-statistics for parameter estimates are given in (), and* p *values for the parameter estimates are given in []. In addition, due to the limited size of the table, only two significant digits after the decimal point are given.*

industrial structure, human capital, market demand, business environment, institutional environment, infrastructure and living environment are significant with a significance level of at least 10%, and the effects are positive. Therefore, for the target cities, improvements in the abovementioned factors will promote competitiveness, but the promotion of competitiveness for each target city will differ. Infrastructure, business environment and market demand play a greater role in promoting the competitiveness of the target cities. A point increase in each factor will promote the competitiveness of the target cities by 0.468, 0.357 and 0.269 percentage points, respectively. The human capital level and living environment are the second most influential factors, with elasticity values of 11.2% and 9.6%, respectively. The institutional environment, second financial service item, technological innovation capability and industrial system play relatively small roles in promoting urban competitiveness, with elasticity values of 7.3%, 6.1%, 0.2% and 0.3%, respectively.

As shown in **Table 2**, The estimation result of the financial service level factor is not significant, but its spatial lag term of −0.25 is negative and significant at the 1% significance level; thus, the financial service level of neighboring cities will be improved, and improvements in the competitiveness of the target city will be impeded. This result arises because the level of financial services is conducive to the normal operation and convenient improvement of urban production and life. Residents tend to choose cities with higher financial service levels for production and life. Similarly, the spatial lags for the business environment and infrastructure are also negative, at −0.34 and −0.28, respectively, with a significance level of at least 10%. Hence, improvements in the business environments of neighboring cities and the quality of their facilities will hinder the competitiveness of the target cities because there is a strong competitive effect between cities. Among the spatial items for all of the variables, only the spatial lag term of human capital is significantly positive, at 0.064; thus, an increase in the human

TABLE 2 | SDM estimation results for space-time double fixed effects for different distance thresholds.

Distance threshold	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	200 km	500 km	800 km	1,100 km	1,400 km	1,700 km	2,000 km
Interpret	−0.25*** (−3.9)	−0.16** (−2.1)	−0.637*** (−3.1)	−0.04 (−0.8)	−1.38** (−2.2)	−2.52** (−2.44)	−1.37*** (−6.51)
Finance	−0.05 (−1.4)	0.018 (0.54)	0.004 (0.11)	−0.04 (−0.92)	−0.09*** (−2.79)	−0.11*** (−2.96)	−0.09*** (−2.54)
finc_squ	0.101*** (3.66)	0.066*** (2.46)	0.05** (2.01)	0.058** (2.12)	0.067*** (2.49)	0.098*** (3.46)	0.087*** (3.12)
Tech	0.005*** (2.93)	0.002* (1.7)	0.003* (1.68)	0.003* (1.88)	0.003* (1.76)	0.004*** (2.89)	0.002** (2.38)
Indust	0.004** (2.14)	0.003* (1.71)	0.004* (1.91)	0.006*** (2.90)	0.007*** (3.35)	0.006*** (2.96)	0.005** (2.09)
Psacp	0.026* (1.88)	0.016* (1.91)	0.017* (1.82)	0.024* (1.78)	0.028** (2.11)	0.036*** (2.61)	0.045*** (3.34)
Demand	0.289*** (10.4)	0.263*** (9.98)	0.281*** (9.94)	0.296*** (10.9)	0.334*** (12.2)	0.315*** (11.24)	0.325*** (11.8)
Business	0.333*** (6.39)	0.345*** (7.02)	0.338*** (8.08)	0.331*** (7.17)	0.297*** (6.13)	0.302*** (5.83)	0.311*** (6.29)
Institute	0.023 (0.62)	0.062* (1.78)	0.108*** (3.29)	0.098*** (3.04)	0.145*** (4.38)	0.107*** (3.14)	0.079** (2.43)
Infrastru	0.343*** (4.78)	0.436*** (6.23)	0.457*** (6.66)	0.474*** (7.29)	0.514*** (8.25)	0.488*** (7.69)	0.435*** (6.85)
Live	0.062* (1.7)	0.073** (2.13)	0.071** (2.08)	0.071** (2.13)	0.095*** (2.98)	0.100*** (2.72)	0.086*** (2.51)
W×finance	−0.06 (−1.15)	−0.38*** (−4.8)	−0.65*** (−5.3)	−0.52*** (−6.2)	−0.44*** (−6.0)	−0.28*** (−5.1)	−0.35 (−0.47)
W×finc_squ	−0.05 (−1.0)	−0.02 (−0.2)	0.566** (2.44)	0.293 (0.76)	0.199 (0.25)	0.18*** (3.57)	0.52 (0.41)
W×tech	0.001 (0.32)	0.005 (1.21)	0.003 (0.51)<	0.012 (1.44)	0.026* (1.84)	0.009 (0.42)	−0.105***(−3.47)
W×indust	0.003 (0.85)	0.011 (1.28)	0.017 (0.91)	0.107***(3.36)	0.081**(1.94)	−0.005 (−0.05)	−0.15*(−1.71)
W×psacp	0.029 (1.26)	0.116*** (3.16)	0.086* (1.74)	0.222*** (2.49)	0.203 (1.35)	−0.04 (−0.15)	−0.64* (1.86)
W×demand	−0.03 (−0.74)	0.203*** (2.55)	0.126 (1.32)	0.101*** (4.71)	0.46*** (5.03)	0.593** (2.01)	−0.91** (−2.2)
W×business	−0.13* (1.72)	−0.21* (−1.7)	−0.25 (−1.0)	−0.26 (−0.6)	−0.85** (−2.1)	−0.09 (−0.08)	0.840 (0.59)
W×institute	0.061 (1.23)	0.172** (2.39)	0.29* (1.73)	0.54** (1.95)	0.79*** (4.77)	0.765*** (2.52)	0.715** (2.23)
W×infrastru	−0.03 (−0.39)	−0.38*** (−3.5)	−0.46*** (−2.6)	−0.99*** (−2.9)	−0.85* (−1.8)	−0.25 (−0.27)	0.845*** (5.14)
W×livelihood	0.021 (0.37)	−0.07 (−0.9)	0.07 (0.59)	0.43* (1.86)	−0.44 (−1.25)	−0.22* (−1.94)	−0.37*** (−3.89)
ρ	0.343*** (5.80)	0.329*** (3.13)	0.279* (1.86)	−0.84 (−2.3)	−0.999** (−2.06)	−0.24 (−0.55)	−0.88 (−1.35)
R^2	0.829	0.839	0.830	0.836	0.837	0.820	0.824
$adj-R^2$	0.823	0.834	0.824	0.830	0.831	0.813	0.817
σ^2	0.010	0.009	0.010	0.010	0.009	0.011	0.011
log-Like	482.23	504.49	488.90	498.18	500.17	472.87	477.65

****, **, and * indicate statistical significance at the 1%, 5%, and 10% significance levels, respectively, and the t-statistic of the parameter estimates is given in (). In addition, due to the limited size of the table, only two significant digits after the decimal point are given.*

capital level will also enhance the competitiveness level of all cities through spillover effects in **Figure 2**.

It is worth noting that the spatial lag coefficient of the interpreted variable ρ is 0.384 and is significant at the 1% significance level. Therefore, improvements in the competitiveness level of neighboring cities have a significant effect on the competitiveness level of the target city. In terms of its promotion strength, except for the investment in the target city's own infrastructure, the competitiveness level of the city is promoted by this factor more than any other individual factor in the target city. This trend highlights an important opportunity for improving the competitiveness of a city: the competitiveness of the target city can be enhanced by improving the competitiveness of neighboring cities.

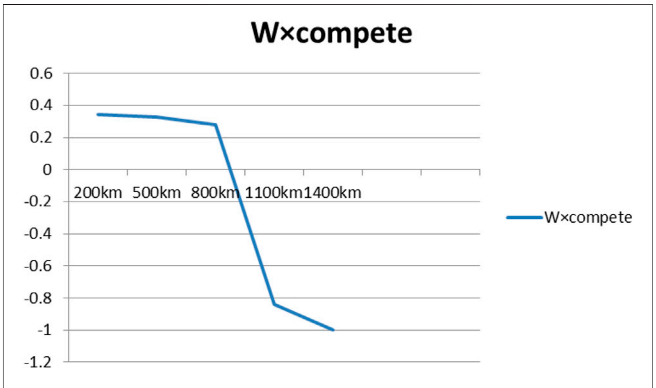

FIGURE 2 | Spatial Attenuation of Neighboring Urban Competitiveness.

Robustness Test

To determine whether the SDM parameter estimation results of the space-time double fixed effect in **Table 1** are robust, the distance threshold matrix is used. Keller (2002) found that technology spillovers are localized rather than globalized, and their impact on economic growth is attenuated as the distance increases; this finding is widely used in studies on the boundary of spatial spillover effects. Concerns and lots of references. On this basis, Rodríguez-Pose and Crescenzi (2008) proposed the optimal distance for space overflow as 3 h of travel time (approximately 200 km). This article follows the approach of Jung and López-Bazo (2017), starting at 200 km and performing a regression for each additional 300 km until the parameter estimation results are no longer significant, up to 2,000 km.

It can be seen in the above table that the SDM estimation results for different distance thresholds have a stronger robustness than the SDM estimation results for space-time double fixed effects. First, in addition to the financial service level elements, promotion of the target city's nine elements, including the second term of its financial services, technological innovation capabilities, industrial structure, human capital, market demand, business environment, institutional environment, infrastructure and living

TABLE 3 | Direct, indirect and total effect estimates of factor inputs.

Distance threshold	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	200 km	500 km	800 km	1,100 km	1,400 km	1,700 km	2,000 km
Direct effect							
Finance	−0.06 (−1.67)	0.012 (0.36)	0.003 (0.09)	−0.025 (−0.73)	−0.09*** (−2.67)	−0.11*** (−2.70)	−0.08*** (−2.51)
finc_squ	0.099*** (3.56)	0.066*** (2.54)	0.059** (2.23)	0.058** (2.04)	0.066*** (2.50)	0.098*** (2.81)	0.084*** (3.03)
Tech	0.005*** (3.07)	0.003* (1.95)	0.003* (1.68)	0.003* (1.78)	0.002* (1.73)	0.005*** (2.97)	0.002 (1.43)
Indust	0.005** (2.02)	0.003* (1.79)	0.004*(1.94)	0.005*** (2.65)	0.007*** (3.32)	0.006*** (2.84)	0.005** (2.01)
Psacp	0.029** (2.03)	0.019* (1.70)	0.019* (1.73)	0.023* (1.76)	0.027** (1.98)	0.036** (2.54)	0.047*** (3.37)
Demand	0.294*** (10.91)	0.269*** (10.1)	0.283*** (9.97)	0.293*** (11.0)	0.329*** (12.7)	0.314*** (10.75)	0.326*** (11.3)
Business	0.331***(6.54)	0.345*** (7.15)	0.388*** (8.22)	0.342*** (7.36)	0.305*** (6.28)	0.299*** (5.76)	0.311*** (6.17)
Institute	0.028* (1.773)	0.064* (1.87)	0.107*** (3.31)	0.095*** (2.91)	0.139*** (4.34)	0.108*** (2.97)	0.076** (2.28)
Infrastru	0.346*** (4.89)	0.432*** (6.30)	0.465*** (6.57)	0.476*** (7.54)	0.518*** (8.33)	0.487*** (7.81)	0.431*** (6.50)
Live	0.066* (1.82)	0.070** (2.07)	0.071** (2.16)	0.069** (2.07)	0.097*** (2.92)	0.099*** (2.61)	0.092*** (2.71)
Indirect effect							
Finance	−0.11 (−1.62)	−0.56*** (−5.56)	−0.91*** (−4.59)	−0.81*** (−7.37)	−0.82*** (−4.09)	−0.56*** (−2.71)	−0.11 (−0.15)
finc_squ	−0.03 (−0.36)	0.002 (0.13)	0.822** (2.34)	0.129 (0.61)	0.047 (0.11)	0.69 (0.37)	0.274 (0.12)
Tech	0.004 (1.04)	0.008 (1.53)	0.005 (0.63)	0.006 (1.11)	0.012 (1.53)	0.011 (0.21)	−0.07 (−0.45)
Indust	0.007* (1.91)	0.018* (1.72)	0.023* (1.85)	0.057*** (2.72)	0.037* (1.69)	−0.012 (−0.07)	−0.12 (−0.26)
Psacp	0.054* (1.83)	0.180*** (3.73)	0.129* (1.69)	0.113** (2.18)	0.087 (1.12)	−0.092 (−0.09)	−0.48 (−0.34)
Demand	0.087* (1.69)	0.427*** (5.65)	0.293*** (2.69)	0.427*** (4.61)	0.544*** (3.12)	0.598 (0.35)	−0.83 (−0.34)
Business	−0.02 (−0.22)	−0.14 (−0.77)	−0.20 (−0.57)	−0.30 (−1.33)	−0.91* (−1.85)	−0.33 (−0.07)	0.232 (0.09)
Institute	0.093 (1.51)	0.289*** (2.65)	0.27** (2.29)	0.248*(1.71)	0.645*** (2.56)	0.271 (0.18)	0.186 (0.378)
Infrastru	0.124* (1.71)	−0.35** (−2.41)	−0.47* (1.91)	−0.78*** (−3.33)	−0.712** (−2.42)	−0.466 (−0.18)	0.116 (0.41)
Live	0.062 (0.866)	−0.06 (−0.53)	0.118 (0.73)	0.214 (1.41)	−0.29 (−1.31)	−0.37 (−0.37)	−0.45 (−0.45)
Total effect							
Finance	−0.16** (−2.4)	−0.54*** (−5.3)	−0.91*** (−4.66)	−0.84*** (−7.86)	−0.91*** (−4.49)	−0.67 (−0.42)	−0.19 (−0.27)
finc_squ	0.072 (0.88)	0.068 (0.41)	0.881** (2.49)	0.188 (0.89)	0.114 (0.25)	0.79 (0.38)	0.358 (0.15)
Tech	0.081** (2.166)	0.011** (2.04)	0.008* (1.94)	0.008* (1.81)	0.015* (1.83)	0.016 (0.30)	−0.07 (−0.44)
Indust	0.011* (1.79)	0.021* (1.69)	0.027* (1.987)	0.062*** (2.92)	0.045* (1.94)	−0.006 (−0.03)	−0.11 (−0.25)
psacp	0.084*** (2.69)	0.199*** (4.18)	0.148* (1.99)	0.136*** (2.89)	0.114 (1.54)	−0.056 (−0.06)	−0.43 (−0.31)
Demand	0.382*** (6.47)	0.656*** (8.82)	0.576*** (5.53)	0.720*** (8.42)	0.873*** (5.15)	0.912 (0.54)	−0.50 (−0.26)
Business	0.309*** (2.88)	0.205 (1.12)	0.182 (0.506)	0.029 (0.12)	−0.61 (−1.22)	−0.03 (−0.01)	0.543 (0.23)
Institute	0.122* (1.94)	0.353*** (3.36)	0.236*** (2.97)	0.343** (2.28)	0.784* (1.89)	0.378 (0.25)	0.261 (0.40)
Infrastru	0.471*** (4.27)	0.083 (0.59)	−0009 (−0.03)	−0.30 (−1.37)	−0.19 (−0.68)	0.021 (0.01)	0.54 (0.46)
Live	0.128* (1.73)	0.008* (1.70)	0.189* (1.72)	0.284* (1.97)	−0.20 (−0.87)	−0.27 (−0.34)	−0.36 (−0.42)

****, **, and * indicate statistical significance at the 1%, 5%, and 10% significance levels, respectively, and the t-statistic of the parameter estimates is given in ().*

environment will promote the competitiveness of the city. Second, not all elements that promote the competitiveness of neighboring cities will promote the competitiveness of the target cities. For neighboring cities, there are only six influential elements: financial services, industrial structure, human capital, market demand, institutional environment and infrastructure. Increased investment can improve the competitiveness level of target cities through spatial spillover, while increases in secondary financial services, technological innovation, business environment and living environment elements in neighboring cities do not promote the competitiveness of target cities through spatial spillover. Upgrade. Third, the spatial lag coefficient ρ of the interpreted variable also has a significant spatial spillover effect, but it is greatly affected by the distance threshold. Specifically, promotion of the competitiveness of the neighboring cities to the level of competitiveness of the target city decreases with increasing distance, with a rapid decline at approximately 950 m, decreasing to −0.999 at 1,400 km, and becoming negligible beyond 1,400 km, as shown in **Figure 2**.

Fourth, the spatial overflow distance for a partial factor input is greater than that for the urban competitiveness level. When the distance threshold is greater than or equal to 1,700 km, improvements in technological innovation capability and market demand in neighboring cities will become a hindrance to the competitiveness of the target cities. Improvements in the infrastructure level of a neighboring city change from hindering to promoting the target city's competitiveness level. Increases in the quadratic term of the level of financial services and institutional environment always promote the competitiveness of the target cities, while improvements in financial services, industrial structure and living environment in neighboring cities always inhibit the competitiveness of the target cities.

INDIRECT EFFECTS AND THEIR MECHANISM OF ACTION

Spatial Spillover Effect and Its Mechanism

Elhorst (2014) noted that when investigating the spatial spillover effect between regions, it is necessary to investigate the feedback

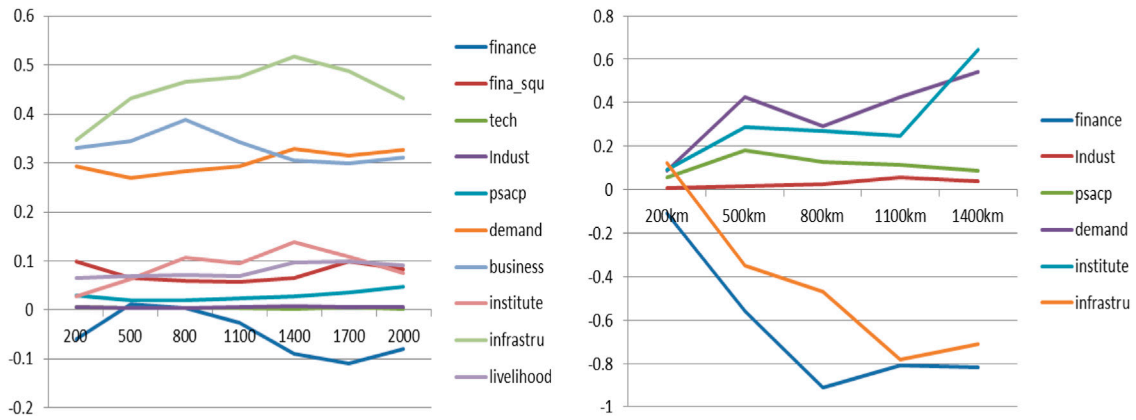

FIGURE 3 | Spatial Attenuation Chart for Direct and Indirect Effects of Urban Factor Inputs.

effect between regions. By calculating the direct, indirect and total effects, including the reflux effect between regions, one can accurately analyze the spatial spillover effects between regions. Therefore, this paper will analyze the factors affecting the competitiveness of the target city by calculating the direct, indirect and total effects. **Table 3** shows the direct, indirect and total effects of different factors for different distance thresholds.

Table 3 shows that the level of financial services affects the level of urban competitiveness, as well as the quadratic term of the level of financial services, technological innovation capabilities, industrial systems, human capital, local needs, business environment, institutional environment, infrastructure and life environment. The ten input factors, including the target city's competitiveness level, do not play a significant role in promoting technological innovation ability at 2,000 km; financial services do not have a significant impact on the city's competitiveness level beyond 1,400 km and will hinder the city's competitiveness if the threshold exceeds 1,400 km. The other elements significantly promote the competitiveness of the target city within 2000 km. Moreover, consistent with the estimation results presented for the SDM in **Table 1**, the infrastructure, business environment and market demand have a greater flexibility in enhancing the level of urban competitiveness, with maximum values of 0.518, 0.388 and 0.329, respectively. The elasticity values of the institutional environment, the quadratic term of the level of financial services and life environment are the second largest, with maximum values reaching 0.139, 0.099 and 0.099, respectively. Technological innovation ability, industrial system and human capital have a relatively small elasticity with respect to the target city's competitiveness level, with maximum values of only 0.005, 0.007 and 0.047, respectively. **Figure 3** shows an attenuation of the direct effects of element inputs on the competitiveness of the target city as the distance threshold increases.

In contrast to the direct impact of elements on the competitiveness level of the target city, not all elements have a significant indirect effect. Among the 10 elements, only the financial service level, industrial system, human capital, local needs, institutional environment and infrastructure had a significant indirect effect on the target city's competitiveness level, while the quadratic term of the level of financial services, technology innovation, business environment and living environment had no significant indirect effect. The six elements with a significant spatial spillover effect can be divided into two categories. The first category includes the market demand, institutional environment, human capital and industrial structure, which have a positive spatial spillover effect over a range of 1,400 km; the spatial spillover effect elasticity value of the institutional environment, human capital, market demand and industrial structure increased from 0.093, 0.054, 0.087, and 0.007 to 0.645, 0.113, 0.544 and 0.037, respectively. As the distance threshold increases, the spatial spillover effect of human capital decreases. The second category includes financial services and infrastructure, with a geographic threshold of 1,400 km; the negative spatial spillover effect of these factors gradually increases with increasing distance, and the elasticity values gradually decrease from −0.11 and −0.35 to −0.82 and −0.712, respectively. In addition, the negative spatial spillover effect of financial services is larger, and the infrastructure only has a positive spatial spillover effect within 300 km. **Figure 2** shows the attenuation of the indirect effect of elements affecting the competitiveness level of the target city with an increasing distance threshold.

In terms of the total effect, the threshold range of the promotion effect of competitiveness level for the target cities is equivalent to that of the indirect effects. For a geographical range of 1,400 km, technological innovation, industrial structure, human capital, market demand, institutional environment and living environment all have a significant positive total effect, with maximum elasticity values of 0.081, 0.062, 0.199, 0.873, 0.784, and 0.284, respectively. The financial service level shows a negative total effect for a range of 1,400 km, with a maximum value of −0.91. The elasticity value of the quadratic term of the level of financial services is only 0.822 for a distance threshold of 800 km, and the elasticity values of the business environment and

TABLE 4 | Spatial spillover effect and its mechanism in cities (同上).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Distance threshold	200 km	500 km	800 km	1,100 km	1,400 km	1,700 km	2,000 km
Interpret	0.471***(8.26)	0.459*** (8.07)	0.454*** (7.96)	0.453*** (7.96)	0.465*** (8.13)	0.047 *** (8.37)	0.489*** (8.55)
Finance	0.119*** (3.69)	0.109*** (3.42)	0.104*** (3.12)	0.098*** (3.02)	0.098** (2.99)	0.100*** (3.05)	0.106*** (3.22)
finc_squ	0.109 ***(3.78)	0.111 *** (3.88)	0.108*** (3.79)	0.104*** (3.67)	0.097*** (3.42)	0.092*** (3.22)	0.090*** (3.13)
Tech	0.003* (1.90)	0.003* (1.72)	0.003* (1.68)	0.002 (1.36)	0.003* (1.69)	0.003* (1.89)	0.003** (2.20)
Indust	0.005*** (2.52)	0.005*** (2.47)	0.005** (2.45)	0.006*** (2.61)	0.006*** (2.76)	0.006*** (2.85)	0.006*** (2.91)
Psacp	0.029** (2.20)	0.025* (1.85)	0.025* (1.87)	0.026* (1.91)	0.028** (2.08)	0.029** (2.17)	0.029** (2.13)
Demand	0.334 ***(12.14)	0.338*** (12.31)	0.336*** (12.32)	0.334*** (12.27)	0.328*** (12.04)	0.323*** (11.86)	0.319*** (11.73)
Business	0.315*** (6.38)	0.308*** (6.25)	0.306*** (6.19)	0.304*** (6.15)	0.317*** (6.43)	0.328*** (6.66)	0.334*** (6.78)
Institute	0.086*** (2.67)	0.089*** (2.74)	0.086*** (2.66)	0.085*** (2.64)	** (2.51 0.081)	0.076** (2.34)	0.069** (2.14)
Infrastru	0.468*** (8.15)	0.446*** (7.68)	0.442*** (7.59)	0.439*** (7.51)	0.457*** (7.83)	0.484*** (8.47)	0.512*** (9.15)
Live	0.118*** (3.56)	0.117*** (0.117)	0.112*** (3.41)	0.107*** (3.26)	0.105*** (3.18)	0.107*** (3.21)	0.111*** (3.32)
Spillover	0.116*** (4.15)	0.112*** (4.65)	0.102*** (4.80)	0.001*** (4.77)	0.001*** (4.12)	0.001*** (3.65)	0.001*** (3.11)
R^2	0.807	0.808	0.809	0.809	0.807	0.806	0.804
$adj - R^2$	0.803	0.805	0.805	0.805	0803	0.802	0.801
σ^2	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Durbin - Watson	1.840	1.839	1.836	1.836	1.842	1.846	1.847

****, ** and * are significant at the 1%, 5% and 10% significance levels, respectively. The t-statistics of the parameter estimations are given in (), and the parameters of the optimal model can be compared upon request to the author. In addition, we give only two significant digits after the decimal point due to the limited table size.*

infrastructure are only 0.309 and 0.471, respectively, within 200 km.

The Mechanism of Urban Competitiveness Improvement

Thus far, we have quantitatively analyzed the indirect effect of different factors with a focus on the factors, and we can see that the spatial spillover effect existing between cities can indeed promote the competitiveness level of the target city. Next, this paper will discuss the promotion spatial spillover effect obtained for cities on the improvement of urban competitiveness with a focus on the cities. Specifically, we calculate the spatial spillover effect for each city and apply it as a variable influencing the urban competitiveness level with other influential parameters, with the help of benchmark OLS regression; we then perform a quantitative analysis of the spatial spillover effect on the competitiveness of the target city. The regression results of the benchmark OLS model are shown in **Table 4**.

Table 4 shows that the spatial spillover effect on a city is regarded as an element input to promote the city's competitiveness, and the benchmark regression is conducted while including other factors affecting urban competitiveness. Within the range threshold of 200–2,000 km, all of the regression $R^2{}_{\text{and}}$ $adj - R^2$ values are greater than 0.8, and the squared error sum is 0.012. Moreover, the results of the Durbin-Watson test are all close to 2; thus, there is no significant collinearity between variables. Therefore, the results of the OLS parameter estimation of the benchmark model are acceptable.

The results in **Table 4** show that the spatial spillover effect for target cities within 200–2,000 km has a significant impact on urban competitiveness, with a maximum elasticity value of 0.116 at 200 km; this effect is equal to the effect of the quadratic term of the level of financial services, the institutional environment and the living environment and greater than the effect of science and technology innovation ability and human capital on urban competitiveness. Within the range of 200–1,200 km, the competitiveness level of the target city is improved, but the competitiveness is hindered beyond 2,000 km. In terms of the magnitude of its promotion effect, the spatial spillover effect between cities within 800 km is highly elastic and promotes urban competitiveness; for distances of 800–1,100 km, rapid attenuation occurs. A positive spatial spillover effect for cities is observed until a distance of 1,200 km is reached, beyond which the effect on the competitiveness level of target cities is reduced to zero. Thus, the distance threshold obtained in this work for the city spatial spillover effect on the urban competitiveness level is basically consistent with the findings of Yu et al. (2016), who reported a production efficiency space attenuation threshold for the clustering of producer services. However, our threshold is smaller than those reported by Gong and Xu, (2017), who reported an elasticity space area of 1,150 km–1,650 km for regional externalities, and Shao and Su (2017), who argued that the overflow effective boundary for the production efficiency of a global value chain is 1,900 km. This result provides us with a useful reference for the hinterland area of urban agglomeration; namely, the hinterland area of urban agglomeration should be controlled within 1,000 km and should not exceed 1,200 km if possible, in order to ensure that cities within the urban agglomeration can make full use of the spatial spillover effect to improve their competitiveness.

For a distance threshold of 200–2,000 km, improvements in the nine elements, including the quadratic term of the level of financial services, science and technology innovation ability, industrial system, human capital, local demand, business environment, institutional environment, infrastructure and living environment, can significantly promote the urban competitiveness level, with maximum elasticity values of 0.111, 0.003, 0.006, 0.029, 0.338, 0.334, 0.089, 0.512 and 0.118, respectively. However, the level of financial services hinders the improvement of the target city's competitiveness, with a maximum elasticity of 0.489.

CONCLUSION

The level of urban competitiveness is the basis for attracting resources and factors, improving urban resilience, and realizing sustainable and rapid urban development. Especially since the outbreak of the new crown pneumonia at the end of 2019, cities that are more resilient and attract more resources and factors have a strong level of economic competitiveness, so that they can quickly resume production and achieve economic development. Anyway, they have fallen into a recession in economic development. Reshape the spatial pattern of Asian cities. Therefore, it is particularly important to quantitatively analyze the influencing factors of urban competitiveness and its impact.

Based on the spatial perspective, this paper uses the SDM method to study the level of economic competitiveness of 565 Asian cities and their spatial spillover effects. The results show that first, the improvement of technological innovation capabilities, industrial system, human capital and other factors will significantly improve the level of economic competitiveness of the city; second, the four factors of industrial structure, human capital, market demand and institutional environment can not only directly improve The level of urban competitiveness will also enhance the level of urban competitiveness through spatial spillover effects; third, the spatial spillover effects of elements have spillover boundaries, and the spillover boundaries of elements are concentrated within a range of 1,400 km. Fourth, the spatial spillover effect of urban economic competitiveness is concentrated in the range of 1,000 km, and the maximum elasticity value is 0.116. Exceeding the spillover boundary will hinder urban competition.

Through the above research, many important enlightenments can be obtained. One is the need to pay attention to the accumulation of factors and the improvement of factor levels in urban development to enhance the level of urban economic competitiveness. The second is to remove barriers to the flow of factors between cities, enhance the mobility of factors between regions, and make full use of the spatial spillover effects of factors to enhance the level of economic competitiveness of cities; third, make reasonable planning and take measures within the radiation range of spatial spillover effects. The multi-center strategy makes full use of the spatial spillover effects of economic competitiveness between cities to achieve an overall improvement in the competitiveness of regional cities.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

CL, MY-PP, and WG, these three authors made substantial contribution to the conception of the work. CL has made significant construction and modifications to the framework of the article, MY-PP checked the English expression of the manuscript, and he was contributed to conceptual design and discussion. WG has made major contributions to the writing, revision and proofreading of papers, and responsible for the contribution.

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Green HR practices and environmental performance: The mediating mechanism of employee outcomes and moderating role of environmental values

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Scholars focused on behavioral changes in employees rather than depending solely on technology enhancements due to organizations' poor and inefficient environmental performance. The purpose of this research is to observe the influence of green HR practices (GHRP) on work engagement and job satisfaction in the environment and its effect on the environmental performance of universities. Furthermore, the mediating effect of work engagement and job satisfaction and moderating impact of environmental values are explored. The data were collected from 337 officials and faculty members of universities of Pakistan through structured questionnaires. The SPSS process macros results indicate that GHRP significantly impacts environmental performance, job satisfaction, and work engagement. The mediation results reveal that work engagement and job satisfaction acted as a means by which GHRP of universities can positively affect environmental performance. The moderation results reveal that environmental values strengthen the relation of GHRP with environmental performance. The study highlights the significance and importance of GHRP for environmental performance and extends the literature by shedding light on the role of employee outcomes and environmental values.

KEYWORDS

green HR practices, environmental performance, job satisfaction, work engagement, environmental values

Introduction

Due to waste of factories, enterprises, and other institutions, the global environment is polluted (Asghar et al., 2021). There is no proper arrangement to demolish the waste and save the environment (Khan et al., 2022a). Previously, human resource management (HRM) was not effective in saving the environment from harmful waste. The environment of the globe is harmful and damages human beings and other living creatures. Nowadays, organizations shift to a green HRM (GHRM) system. The objective of GHRM is to save the environment and adequately degrade waste. Our universities and educational institutions produce massive waste, including paper, plastics, and environmental waste materials. Education institutions must improve environmental performance by concentrating on developing employees' environmental capabilities and behavior.

Environmental performance studies seem to be the most significant hazard for sustainability in the modern world's mechanical pollution (Xiang et al., 2011). However, existing research highlights that specific drivers and boundaries frequently affect firms eagerly receiving natural hones and accomplishing supportability. The fulfillment of green certifications and appropriation of the environmental controlling system are a few drivers that move forward firms' journey supportability (Jabbour, 2013). Such drivers do not only encourage firms' capacities to meet environmental goals but also emphatically impact their monetary execution (Jacobs et al., 2010). However, many businesses continue to view environmental initiatives as a burden on their potential benefits and rely on quick compliance measures to achieve their objectives (Marcus and Fremeth 2009).

Environmental concerns can be mitigated by advancing the concept of GHRM. HR is critical in communicating optimal management vision to other parties. The management must work together at the corporate center and corporate line to achieve corporate goals. Nevertheless, HRM's role in environmental success is crucial because it directly impacts the execution of these green measures (Paillé et al., 2014). The ability, motivation, and opportunity (AMO) theory led this empirical research by offering a theoretical foundation for how HR practices develop employees' environmental skills and motivation and opportunities for increasing environmental performance (Yu et al., 2020). Green HR methods such as eco-staffing, e-recruiting, and eco-training have been studied extensively in the manufacturing industry (Kim et al., 2019). Two more perspectives on service industries have been discussed in prior literature: those of customers and those held by service workers (Fawehinmi et al., 2020). Research on employee awareness and attitude toward implementing green practices is limited, and there is a need to explore it further. Based on recent calls, the study attempts to inspect the green HR practices (GHRPs) of universities as this sector is yet neglected (Fawehinmi et al., 2020).

However, the GHRP is inadequate for increasing environmental performance (Singh et al., 2020). To fulfill the research gap, there is a need to explore some intervening mechanisms that may further augment environmental performance (Liu et al., 2020). Employee work engagement and job satisfaction may strengthen the relationship between GHRP and environmental performance (Anwar et al., 2020). Work engagement has improved environmental performance (Schaufeli and Bakker, 2010). Sustainability in environmental performance depends on employee behavior (Kim et al., 2019). A person's job satisfaction may negatively or positively impact reliance on the work environment and interpersonal interactions (Khan et al., 2022b). According to Adigun et al. (2017), work satisfaction impacts employee and environmental performance.

In addition, environmental values also increase the link between GHRP and environmental performance. Modern green value literature has emphasized the importance of individual values on the attitudes and behaviors of those who hold them (Davidov et al., 2008). Their eco-friendly behavior is heavily influenced by their care for the environment (Chou, 2014). In the past, researchers have shown a link between personal values and performance in terms of the environment (Schultz et al., 2005; Chou, 2014). Thus, this study also examines the moderating role of environmental values in GHRP and environmental performance.

In context-specific learning, universities integrate environmental administration concepts into their operations, instructional prospectus, research programs, building plans, and other campus activities to recognize their environmental responsibility (Mikulik and Babina, 2009). Environmental statements have affirmed these principles; as a result, their progress toward maintaining their systems continues to be extremely slow (Lozano et al., 2013). Universities have paid relatively less importance to the behavioral components of environmental execution management (Khan et al., 2021). There is minimal exploration of the effects of GHRM on employee performance (Yong et al., 2019).

According to Lozano (2006), many university leaders and staff members are unaware of sustainably oriented development concepts and their execution in universities. They gave less attention into integrating sustainably oriented standards into courses, research, and outreach activities. The professors and other university staff were essential partners in the university setting (Lozano, 2006). Environmental sustainability should be incorporated into the university's framework globally. In reality, this is difficult to achieve in the early phases of integrating environmental sustainability into a university's framework. This can be accomplished by identifying and empowering a few people involved in small projects to exchange their experiences and information. Instructors can also have a multiplying effect on being educated to educate other teachers (Lozano, 2006). Recently, Fichter and Tiemann (2018) identified

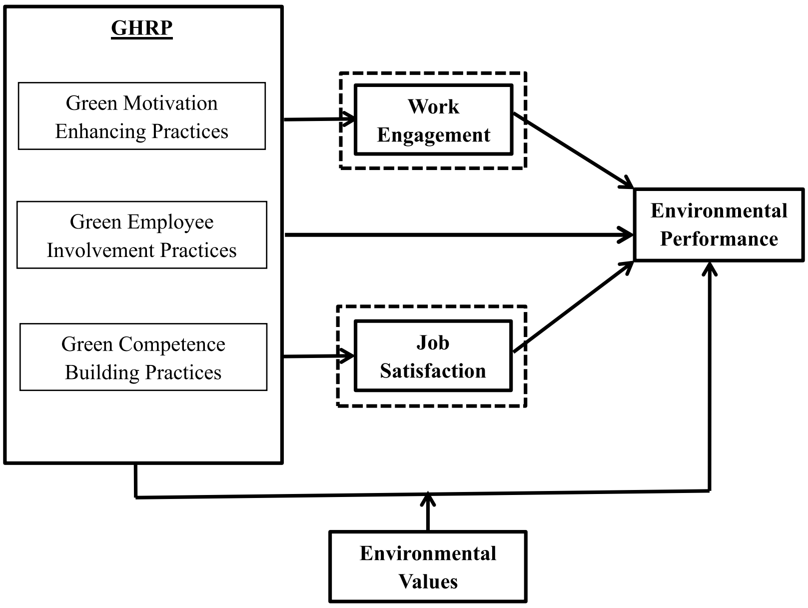

FIGURE 1
Theoretical framework.

key persons in university administration and the workforce as initiators, promoters, and networkers as variables that enable sustainable changes in universities.

Based on AMO theory, the aim of the present study is, thus, to investigate how GHRM plays a critical role in the environment-friendly behavior of employees in higher education institutes, particularly in Pakistan. We aim to test a theoretical framework (Figure 1) empirically. Furthermore, the study examines the mediating mechanism of employee outcomes (work engagement and job satisfaction) and the moderating role of environmental values. More specifically, the study addresses three research questions: first, does GHRP influence environmental performance? Second, does work engagement and job satisfaction mediate the relationship between GHRP and environmental performance? Finally, do environmental values moderate the relation of GHRP with environmental performance?

Literature review

GHRP and environmental performance

GHRP involves three dimensions: first, green competence building; second, green motivation enhancing practice; third, green employee involvement practice. GHRM becomes challenging if firms try to clarify green challenges on an expedient basis. It leads to optimal green performance (Jabbour, 2013). A firm may adopt a technology or other environmental management solutions without making any organizational changes. It is a trend that will only get stronger as employees become more environmentally aware and firms begin implementing workplace policies (Crane et al., 2008). People's behavior, production, and consumption patterns are said to be responsible for around 40% of the problems with the atmosphere (Gan et al., 2008). Previous research has long linked global environmental degradation to economic development and human activity (Kinnear et al., 1974; Grunert 1993; Gan et al., 2008).

People must exhibit certain behaviors and attitudes to perform effectively (Wood 1997; Brownell 2008; Zopiatis 2010). Employees' willingness to engage in green behavior may be influenced by their personal preferences and environmental belief (Pichel, 2008). Employment happiness increases when employees' ethical and environmental ideals align with those of the firm's (Hoffman, 1993; Chou, 2014). Based on the findings, mild persuasion will be more effective than rigorous organizational policies, practices, and regulatory mandates in motivating people to adopt green behaviors (Lillo Banuls et al., 2018). As a result of prior experiences, an individual has acquired green competencies, which include qualifications, education, tacit knowledge, professional information on environmental concerns, and feelings that encourage them to acquire and behave environmentally friendly (Cousins et al., 2008). On the other hand, official education and training/ development aid in restoring knowledge and green behavior, allowing individuals to change and display green behavior and attitudes in general (Chou, 2014).

Enabling workers to achieve their goals can increase motivation, resulting in more productive employees, and inspiring workers to achieve their personal and organizational goals by providing them with motivation and engagement (Tariq et al., 2016). The environmental orientation shows how environmental protection organizations work and motivate environmental concerns, which should be part of their strategy (Banerjee et al., 2003). Research reveals that environmental groups can concentrate internally and internationally. An internal environmental organization also concentrates on the extent to which the organization attaches priority to environmental sustainability challenges. GHRP significantly influences environmental performance and leads to greater efficiency, cheaper costs, and increased employee commitment (Kim et al., 2019). Relying on the aforementioned discussion, GHRPs are expected to affect environmental performance.

H1. GHRP positively affects environmental performance

GHRP and work engagement

GHRM practices are helpful in achieving green goals and fostering constructive work conduct (Hobfoll, 2001; Jabbar & Abid, 2015). Organizations integrating GHRM practices can distress employees' performances toward being green (Renwick et al., 2013). Scholars discovered that engagement in green work arises from the support of supervisors and good management of HR, such as green awards and green training (Cantor, et al., 2012). Goodness in GHRM encourages employees to show productive green behaviors and convinces them to come up with fresh ideas and new green solutions (Aboramadan et al., 2020). GHRM may stimulate growth of employees and their career objectives, such as an achievement that promotes the commitment to work between employees (Arasli et al., 2020).

Likewise, Cantor et al. (2012) noted that green work engagement is the consequence of assistance by supervisors and management of HR such as green recompenses and green education. Green work engagement is a significant result of GHRM as such activities are assessed by employees in an organization (Ari et al., 2020). The environment should be considered for a successful business, and specific HRM practices may be established. The present study emphasizes the influence of GHRP on work engagement. GHRP is crucial in sustainable corporate development (Dumont et al., 2016). Environment-friendly GHRP improved efficiency and workplace engagement (Deshwal 2015). This shows that employees are more engaged in the work with GHRM practices. GHRM can, therefore, be viewed at work as a motivating factor with a positive connection to employees' engagement (Schaufeli and Bakker, 2003).

GHRP would help achieve green goals and foster great work habits (Hobfoll, 2001; Jabbar & Abid, 2015). Work engagement is an outcome of supervisors' support and strong HRM practices (Cantor et al., 2012). Excellence in GHRM inspires employees, improves their ability to show optimistic green behaviors, and urges them to develop innovative thinking at the green level (Aboramadan et al., 2020). GHRP also motivates workers (i.e., extrinsically and organically supporting their growth) and increases employee dedication and especially work engagement (Bakker Arnold and Demerouti, 2008).

HR practices should be carefully built by considering the environment for a successful organization. GHRPs are critical to a company's long-term feasibility (Dumont et al., 2016). GHRM improves higher productivity and employee engagement at work (Deshwal 2015). Employees become more devoted and engaged with work when GHRM practices are implemented. According to Dutta (2012), green HR contributes to engagement. Green practices have a good relationship with employee job engagement. Thus, we hypothesized that GHRP influences work engagement.

H2. GHRP positively affects work engagement

Work engagement and environmental performance

Pro-environmental behaviors are based on mutual support by employees for an organization's environmental issues, such as the voluntary exchange of ideas, expertise, and teamwork to identify pollution sources and preventative measures. The understanding and knowledge of employees usually appear to influence an organization's decision-making and intents. Employees often avoid being a part of situations they do not know (Otto & Pensini, 2017). Furthermore, awareness of environmental issues makes individuals socially responsible through support for environmental behaviors and influences the environmental performance of organizations (Zareie and Avimipour, 2016). People with environmental consciousness tend to contribute their part to environmental protection through spending on natural, green, and organic products, recycling, and green activities. Environmental knowledge affects pro-environmental behavior intentions. The person seeking supplementary knowledge appears to participate in environmental behavior (Zareie and Avimipour, 2016). Therefore, work engagement may influence pro-environmental behavior and environmental performance at the workplace.

The scholars examine the impact of green HR policies in manufacturing organizations on environmental performance (Chaudhary, 2019). The literature reveals that reducing waste in GHRP and educating staff on water and energy supply conservation influence environmental performance (Roscoe et al., 2019). Environmental training enhances staff awareness of environmental policy implementation. Green compensation and awards make it easier for employees to reduce excessive use of office material, trash disposal, energy and water preservation, and light disruption. Sustainability in environmental performance depends on employee behavior (Kim et al., 2019).

The significance of ecological execution is alleged to represent a decent opportunity in a win–win state to improve an organization's sustainability. Green practices can improve implementation and work engagement in businesses (Jackson et al., 2014). Some studies have shown that GHRM and green production are cross-cutting to accomplish environmental performance (Amui et al., 2017). It is also found that GHRM inspires people to perform their job under the umbrella of green practice, which is the best approach to achieving work engagement and improving environmental performance. Therefore, we propose that work engagement affects environmental performance.

H3. Work engagement positively affects environmental performance

GHRP and job satisfaction

Social exchange theory (Blau et al., 1964) explains how employees' opinions of socially accountable HR practices affect their job satisfaction. The 'norm of reciprocity' in social connections is the foundation of the social exchange theory. If an employee receives economic or socio-emotional advantages from HR functions from their employer, then they reciprocate similarly (Blau et al., 1964). Employees consider an organization's HR processes a personalized commitment (Gong et al., 2010). They are obligated to respond positively. HR procedures influence employees' attitudes and actions. Socially responsible HR practices are essential and positively influence commitment (Nishii et al., 2008).

Job satisfaction is critical for companies to acquire a competitive edge in all sectors as employees play a crucial role in corporate success (John et al., 2022). However, there is no broad consensus concerning its description, despite the significance of job satisfaction. Satisfaction with work depends on aspects such as personal, corporate, administrative, academic, and business characteristics.

Psychologists focused on employees' satisfaction with the work investigated. Happiness for employees is improved by increased employee compensation, the assessment system, the promotion plan, and the training and development program (Sharma et al., 2014). The past study focused on the most satisfactory event for employees in the position of staying and leaving the firm and assessing job satisfaction. The survey found that employee happiness and productivity in occupations are even higher than in less difficult ones (Zopiatis, 2010).

Employee well-being and productivity correlate with job satisfaction and staff happiness (Platis et al., 2015). GHRP can encourage employees and increase organizational productivity. According to studies, job satisfaction and employee perceptions of the organization's social responsibility initiatives are positively correlated (Martin and GertRoodt, 2017). Based on the aforementioned discussion, we propose that GHRP influences job satisfaction.

H4. GHRP positively affects job satisfaction

Job satisfaction and environmental performance

The type of work, work environment, and interpersonal interactions can positively or negatively impact a person's job satisfaction (Gibson et al., 2011). It has been shown that employee happiness is higher when there is a healthy workplace and welfare, whereas employee dissatisfaction negatively impacts the organization (Bentley et al., 2013). Work satisfaction impacts both employee performance and job satisfaction (Adigun et al., 2017). Job satisfaction and employee performance have a positive relationship (Platis et al., 2015; Bakotic, 2016).

Performance management is the entire process of managing to increase an organization's productivity and the productivity of each employee and workgroup (Rachman et al., 2020). This helps employees identify and solve work problems (Mackey and Johnson, 2000). Regarding organizational behavior and HRM, job satisfaction is a critical factor. As a result of job satisfaction, workers are more likely to be happy, morale, and motivated (Mabaso & Dlamini, 2017). Workplace pleasure is a deeply felt personal experience and leads to high performance. On the other hand, companies must fulfill their goals.

Employee performance and job satisfaction are correlated. As prior research indicates, there is a positive correlation between job satisfaction for the salary payment system and employee performance (Owusu 2014). Furthermore, Roberts (2008) utilizes five factors to gauge satisfaction: contentment with superiors, coworkers and the work itself, advancement chances, and money. The strength of organizational performance management is its ability to provide results. Performance management is an activity carried out to increase an organization's productivity and the productivity of each employee and workgroup (Rachman et al., 2020). This helps employees identify and solve workplace problems (Mackey and Johnson, 2000).

It is easier for employees who are happy to participate in green initiatives if they feel supported. Those people who are happy in their jobs are more likely to take environmental responsibility seriously, which leads to higher involvement in green initiatives and an overall improvement in environmental performance (Ahmad, 2015). Settled employees are more likely to be interested in their work than dissatisfied employees. In other words, if workers are settled with their jobs, they will be more likely to participate in green initiatives and lessen their environmental impact.

H5. Job satisfaction positively affects environmental performance

Mediating role of work engagement and job satisfaction

It has been demonstrated that work involvement is an essential mechanism of happiness (Aboramadan et al., 2020). Involvement and motivation in the workplace are typically considered to be performance-enhancing factors, thereby enhancing the potential of employees to engage in positive eco-behaviors (in-role or voluntary) and encouraging them to attempt new things that could be developed. According to the social exchange theory, new thoughts, and substitutes on the green level, employees with higher levels of involvement are more likely to engage in quality social exchanges with their company. It is a win–win situation for employees who want to go green (Saks, 2006). Good impressions of GHRM boost employees' green work engagement.

People engage in their work and perform well at their jobs. Individuals' tenacity and intensity in pursuing their task performance should be tied to engagement as it is a motivational notion (Rich et al., 2010). The engaged workers are active participants, feel proficient, and have high ambitions (Albrecht, 2010). Pleasant emotions help people focus on their tasks and attain high levels of individual achievement. These individuals are also sociable and helpful, which enhances the complete effectiveness of those who operate in teams (Bakker Arnold and Demerouti, 2008). Their high level of engagement donates to their well-being and accompanying work capability (Demerouti et al., 2001). Resilience enhances work engagement, which further enhances job performance (Othman et al., 2013; Mache et al., 2014). Extant research highlights that there is a favorable link between work engagement and contextual and task job performance (Schaufeli and Bakker, 2010; Mache et al., 2014).

When workers have an attitude toward their jobs, they are healthier and more satisfied with their lives (Judge & Watanabe, 1993; Faragher et al., 2005). Worker satisfaction has been linked to better relationships with colleagues (Swider et al., 2011), fewer absences (Steel et al., 2002), and a lower likelihood of quitting (Swider et al., 2011). It is also linked to a higher organizational commitment (Judge et al., 2001; Yoon & Thye, 2002). Resistant behavior reduces the negative impact of stress on job satisfaction (Krush et al., 2013). Resilient people can successfully manage their emotions when faced with adversity (Bonanno et al., 2001). Moreover, resilient persons have higher levels of positive emotions than less resilient people when faced with a stressor (Cohn et al., 2009).

Positive feelings about one's employment should allow people to operate more successfully and efficiently for better performance. Conversely, employees who are unhappy with their jobs and spend a lot of time dealing with their negative feelings cannot perform. After experiencing pleasant emotions, one's viewpoint and perception of situations are broadened and more realistic (Fredrickson, 2004). Consequently, this study examines the intervening mechanism of work engagement and job satisfaction between GHRP and environmental performance.

H6. Work engagement mediates the relationship between GHRP and environmental performance

H7. Job satisfaction mediates the relationship between GHRP and environmental performance

Moderating role of environmental values

The literature on green values has stressed the significance of personal values on attitudes and behaviors (Davidov et al., 2008). Their eco-friendly behavior is heavily influenced by their care for the environment (Chou, 2014). In the past, researchers have shown a link between personal values and performance in terms of the environment (Schultz et al., 2005; Chou, 2014). Work behavior is influenced by individuals' beliefs, values, and norms (Stern et al., 1999).

The extant HR behavioral research reveals that one's traits may operate as an amplifier or deterrent to the relationship between HR practices, individual behavior, and organization performance. The individuals' perceptions, values, and needs and the organization's customs, practices, and goals determine the individual's behavior (Paille and Borial, 2013). Employees who are more inclined to be involved in in-role and extra-role maintain ability-related duties and activities if the environmental context is considered (Dumont, et al., 2017). However, regardless of the importance of this topic, the number of studies that indicate the moderating effect of personality factors on GHRM and individual attitudes is still lacking.

Individual green values modulate the link between GHRM practices and psychological green climate (Dumont et al., 2017). On the other hand, people's personalities significantly influence their thoughts, feelings, and behaviors more than their values, which fluctuate with environmental changes (McCrae and Costa, 2003). The individual's values reflect their motivations, not behavior (Roccas et al., 2002).

Personal and organizational characteristics influence employee attitudes toward the organization's environmental values and goals and green behavior (Huertas-Valdivia et al., 2018). In the workplace, positive traits affect vigor and enthusiasm for life (Watson et al., 1988). When people are more optimistic about GHRM practices, they are more likely to cope positively and actively with the organizational environmental demands (Huertas-Valdivia et al., 2018).

Employees' attributes and HRM's green activities encourage energy, vigilance, enthusiasm, and dedication at work. Like a proactive mentality, opportunists, action-takers, and savers are unafraid of situational hurdles (Bateman and Crant, 1993). Additionally, green conduct requires pro-environmental behavior, where employees must go above and beyond statutory organizational behavior requirements and demonstrate ground-breaking behaviors (Yu and Yu, 2017).

Therefore, a better connection between HRM green values and actions and individual positive skills might influence employee participation in environmental projects.

Employees' environmental enthusiasm makes them better workers, positively impacting their performance. In addition, this relationship will be improved if employees place high importance on environmental values. Therefore, the study proposes the following hypothesis:

H8. Environmental values moderate the relationship between GHRP and environmental performance.

Methodology

Population and procedures

The study's target population is employees of both public and private sector universities in the Punjab province of Pakistan. The primary data were gathered using a structured questionnaire. Universities in Pakistan have the same structure, regulations, and culture. Hence, statistics from the Punjab province maybe presumed to reflect the entire population. University employees consist of both teaching and nonteaching officials. By utilizing the convenience sampling technique, 450 questionnaires and cover letters were distributed among respondents of universities in the Punjab province. The researchers initially distributed questionnaires to employees of universities *via* Google forms, emails, WhatsApp, and other social media websites. Finally, the researcher physically visited the respondents in their respective departments and offices. This process continued for almost 2 months, and finally, 337 useable questionnaires were received, which is an actual sample of the study.

Measurement and scales

This study focuses on three GHRPs measured by the 13-item scale of Tang et al. (2017). Environmental performance is measured by utilizing the 12-item scale of Larran Orge et al. (2016). To measure job satisfaction, a 16-item scale developed by Dziuba et al. (2020) is adopted. The 16-item scale measures work engagement by Schaufeli and Bakker (2003). Environmental values are measured using a 7-item scale by Steg et al. (2005) and Stern et al. (1999). Participant's personal information, such as their age, formal education, and work experience, could also influence their counterproductive behavior, perception of justice, and personality traits, so these personal characteristics are used as control variables.

Results

Initially, the data were screened out for missing values and outliers. Data normality is tested through KMO and Bartlett's test. The KMO results 0.936 reveal that data are normal for further analysis.

Descriptive statistics and correlations

The mean and standard deviation values of all variables can be observed in Table 1. The scale reliability is tested through Cronbach's alpha. The results reveal that (Table 1) alpha values of GHRP are 0.90, environmental performance 0.89, work engagement 0.90, job satisfaction 0.90, and environmental values 0.86. All these values are good and within an acceptable range.

The correlation matrix (Table 1) provides the initial support for the proposed hypotheses. Our first hypothesis proposes the relationship between GHRP and environmental performance. The results show that GHRP is positively and significantly correlated with environmental performance (coefficient = 0.705, p < 0.01). The second hypothesis states that GHRP positively affects work engagement. The results show that GHRP significantly and positively affects work engagement (coefficient = 0.717, p < 0.01). Our third hypothesis is the positive relationship between work engagement and environmental performance. The results proved that there is significant and positive relationship (coefficient = 0.592, p < 0.01). The fourth hypothesis is that GHRP positively affects job satisfaction. The results reveal that the relationship between them is significant and positive as the value shows that the coefficient is 0.573, p < 0.01. Our fifth hypothesis is the positive association among job satisfaction and environmental performance. The results demonstrate a strong and favorable connection between job satisfaction and environmental performance (coefficient = 0.659, p < 0.01).

Process macros results

The researcher used Process Macros Model 5 (Hayes, 2013) to test the hypothesized relations (Table 2). The outcome shows that GHRP has a significant and positive effect on environmental performance (β = 0.887, p < 0.01 [LLCI = -1.207, ULCI = -0.567]). Thus, hypothesis H_1 is supported (Table 2). Furthermore, results reveal that GHRP has a significant and positive effect on work engagement (β = 0.561, p < 0.01 [LLCI = 0.502, ULCI = 0.619]). Thus, H_2 is also fully supported (Table 2). Furthermore, we hypothesized that work engagement has a positive effect on environmental performance. The findings show that work engagement has a significant and positive effect on environmental performance (β = 0.367, p < 0.01 [LLCI = 0.219, ULCI = 0.516]). Therefore, H_3 is supported by our data (Table 2). The results of hypothesis 4 reveal that GHRP has a significant positive effect on job satisfaction (β = 0.494, p < 0.01 [LLCI = 0.417, ULCI = 0.570]). Thus, hypothesis H_4 is supported (Table 2). The results of hypothesis

TABLE 1 Descriptive statistics and correlation matrix.

Variable	Mean	SD	1	2	3	4	5	6	7	8
1. Gender	0.64	0.48	1							
2. Education	17.64	1.77	-0.194**	1						
3. Tenure of Job	8.84	6.96	0.255**	-0.360**	1					
4. GHRP	3.89	0.69	-0.106	0.117*	-0.003	(0.90)				
5. EP	3.96	0.71	-0.061	0.067	0.016	0.705**	(0.89)			
6. WE	4.16	0.54	-0.124*	0.143**	-0.055	0.717**	0.592**	(0.90)		
7. JS	4.14	0.60	-0.132*	0.158**	-0.050	0.573**	0.659**	0.610**	(0.90)	
8. EV	4.19	0.66	-0.123*	0.132*	-0.065	0.577**	0.422**	0.722**	0.556**	(0.86)

Notes: GHRP, Green HR practices; EP, environmental performance; WE, work engagement; JS, job satisfaction; EV, environmental values, alpha values along diagonal in parenthesis.

TABLE 2 Process macros results.

Hypothesis	Path	Direct effect			Indirect effect		
		Beta	LLCI	ULCI	Beta	LLCI	ULCI
H1	GHRP EP	0.887**	-1.207	-0.567			
H2	GHRP WE	0.561**	0.502	0.619			
H3	WE EP	0.367**	0219	0.516			
H4	GHRP JS	0.494**	0.417	0.570			
H5	JS EP	0.382**	0.279	0.486			
H6	GHRP EP *via* WE				0.206	0.092	0.336
H7	GHRP EP *via* JS				0.189	0.104	0.283
H8	Int. effect of EV	0.352***	0.280	0.424			

Notes: GHRP, Green HR practices; EP, environmental performance; WE, work engagement; JS, job satisfaction; EV, environmental values; $^{**}p < 0.01$.

5 state that job satisfaction has a significant positive effect on environmental performance ($\beta = 0.382$, $p < 0.01$ [LLCI = 0.279, ULCI = 0.486]), so hypothesis H_5 is fully supported (Table 2).

Moreover, an indirect effect of work engagement and job satisfaction between GHRP and environmental performance is tested. The results of hypotheses H_6 and H_7 again supported the mediating mechanism of work engagement and job satisfaction between GHRP and environmental performance ($\beta = 0.206$, $p < 0.01$ [LLCI = 0.092, ULCI = 0.336]) ($\beta = 0.189$, $p < 0.01$ [LLCI = 0.104, ULCI = 0.283]). It can be observed that both upper level and lower level of confidence intervals are positive. Thus, hypotheses H_6 and H_7 are fully supported by our data (Table 2).

Hypothesis H_8 shows that environmental values moderate the relationship between GHRP and environmental performance. The positive effect of GHRP on environmental performance is strengthened when environmental values are high ($\beta = 0.352$, $p < 0.01$ [LLCI = 0.280, ULCI = 0.424]). Therefore, hypothesis H_8 is also supported (Table 2). The moderating effect of environmental values is plotted in Figure 2.

Discussion

The current research investigated the effect of GHRP on environmental performance in universities in Pakistan. Based on the AMO theory, we investigated how GHRP, work engagement, job satisfaction, and environmental values increase the environmental performance of the universities. This study also aims to investigate the role of job satisfaction and work engagement as mediators between GHRP and environmental performance. Moreover, it is found that environmental values moderate the relation of GHRP with environmental performance. The results validate the proposed model.

We examined the impact of GHRP on environmental performance. Findings show that GHRP positively influences the employees' environmental performance. This finding is in line with the recent results of Ari et al. (2020). This study investigated the impact of GHRP on work engagement. We tested the effect of GHRP on job satisfaction. The empirical evidence shows a significant influence of GHRP on job satisfaction. This indicates that GHRP significantly influences

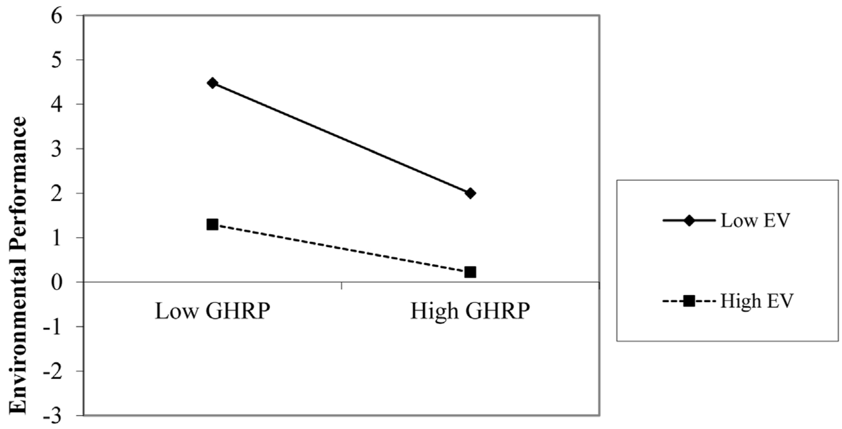

FIGURE 2
Moderation effect of environmental values.

the job satisfaction of the employees of the universities. Recent research also suggests a positive impact of GHRP on job satisfaction. Therefore, GHRP adopted by educational institutes can improve employees' job satisfaction.

The intervening effect of work engagement is also examined. The empirical evidence reveals that work engagement mediates the relationship between GHRP and environmental performance. This result is as per the theoretical foundation and novel findings of the study. We tested the effect of GHRP on environmental performance through job satisfaction. Empirical evidence from the study shows that job satisfaction plays an intervening role between GHRP and environmental performance. Our study found that the environmental performance level enhances when job satisfaction exists between GHRP and environmental performance.

The effect of work engagement and job satisfaction on environmental performance is also examined. The findings show that work engagement has a favorable, significant, and desirable effect on environmental performance. As a result of their work engagement, the environmental performance of the universities was enhanced. Therefore, work engagement is very important to achieve and increase environmental performance (Hanaysha, 2016). The findings also suggest that job satisfaction influences environmental performance. When workers are not happy with their jobs, they would not be able to utilize their complete energy to get better outcomes. When employees were happy with their jobs, the environmental performance increased. Finally, the moderation effect of environmental values is also examined. The results demonstrate that there is a strong relationship between environmental performance and GHRP. Environmental values are shown to improve the link of green HR strategies with environmental performance.

In various areas, this study extends to the emerging literature on green HR. First, it investigates the interrelationship among GHRP, work engagement, job satisfaction, and environmental performance. Second, it achieves the current research gap by examining the intervening mechanism of work engagement and job satisfaction among GHRP and environmental performance. Third, it enhances the literature by testing the moderation of environmental values among GHRP and environmental performance. Finally, this study targets higher education institutions, a sector where empirical literature is scarcely available.

Implications

Theoretically, by improving knowledge about green management, this study extends the body of literature, which became a global issue in the last few years. According to scholars, GHRP can help the organization meet its environmental goals. Slight attention has been given to find out how GHRP and environmental performance are linked. When employees are well-trained in how to implement environmental initiatives, they seem to be more likely to go above and beyond their job responsibilities to help their company be more environmentally friendly. Furthermore, this study provides empirical evidence in view of the theoretical lens of AMO.

Practically, this study is helpful for practitioners and higher authorities of the universities to increase their environmental performance by providing job satisfaction and work engagement to their employees. Higher authorities of HR departments may implement this research for the recruitment and selection process for new intakes. Authorities prefer to select and recruit vigilant and environment-conscious candidates. This study is also helpful for managers to save resources and shield the environment by reducing the use of environmental waste materials (e.g., papers, plastics, etc.). According to this research, the contribution of various GHRPs to work engagement and job satisfaction may be quantified and communicated to university stakeholders. The study's findings will aid university administrators in developing HR practices that cheer students and faculty to adopt pro-environmental attitudes and behaviors. A university's environmental attitude might be emphasized through green recruitment practices to attract applicants with an environmental mindset.

Limitations and research directions

Apart from significant contributions, there are some limitations. The first limitation is that data are collected from the employees of the universities. In future, other sectors may also be targeted. Second, this study focuses only on three GHRPs. Future studies can use other GHRPs such as career planning, compensation, and performance appraisal. Third, we have examined the combined effect of all three practices; in future, the impact of each HR practice may be investigated on other variables. Fourth, this study investigated the mediating effect of work engagement and job satisfaction to understand the relationship between GHRP and environmental performance. Future research may focus on other mediating mechanisms such as employee motivation and performance. Finally, this study tested the moderating effect of environmental values among GHRP and environmental performance. Future studies may focus on other moderating mechanisms, such as the green experience.

Conclusion

Higher education institutions have acknowledged that failing to address human or behavioral aspects in their environmental endeavors would result in ineffective environmental performance. However, there is a dearth of research to direct the effective use of behavioral treatments in executing university environmental policies. Generally speaking, this study's objective was to link GHRP with the environmental performance of universities. Universities are known as leaders of knowledge creation, and the recent study addressed the idea of GHRP as enhancing motivation, the ability to build an opportunity to provide the practices which have the potential to influence employee's work engagement and job satisfaction. Findings illustrate the favorable effects of GHRP, work engagement, and job satisfaction on environmental performance. The findings provide fruitful results for policymakers to consider work engagement, job satisfaction, and environmental values for employees to demonstrate such behaviors that increase environmental performance. This study also offers recommendations for setting up GHRM policies at the organizational level to make their human capital ecologically responsible and increase employee knowledge of the need to protect natural resources like water and electricity.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

Muhammad Adeel wrote the initial draft of the manuscript. Shahid Mahmood analyzed the data and supervised the project, Kanwal Iqbal Khan helped in data collection and final write-up, Saima Saleem re-reviewed the overall manuscript and helped in handling review reports.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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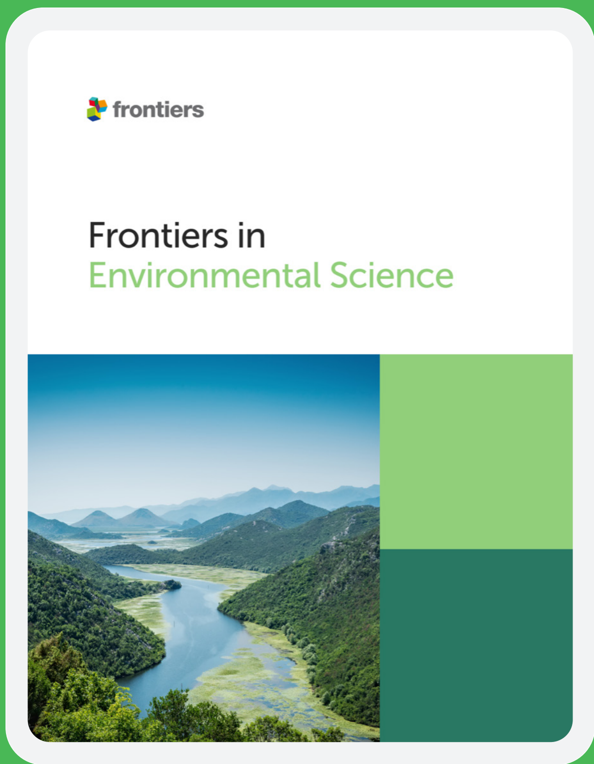

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