Environmental Science and Pollution Research (2023) 30:11675–11688
https://doi.org/10.1007/s11356-022-22952-7

RESEARCH ARTICLE

Promoting green economy efficiency through fiscal decentralization and environmental regulation

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Received: 25 June 2022 / Accepted: 5 September 2022 / Published online: 13 September 2022

Abstract
The paper selects the data of 30 regions in China from 2008 to 2020 as the basis to construct a theoretical analysis framework between fiscal decentralization, environmental regulation, and green economy efficiency (GEE). For empirical analysis, the study adopts super-slacks-based measure (SBM) method to measure GEE, and Tobit model is adopted to study the relationships between key constructs under investigation. The key findings of the study are as follows: (1) GEE level is at the upper middle level, and the green economic efficiency varies greatly among regions. The GEE value of the eastern region is the highest and lowest in the west, and the central region is in between. (2) From a national perspective, fiscal decentralization, environmental regulation, per capita gross domestic product (GDP), and urbanization all have a significant negative coefficient on the national GEE, inhibiting local GEE improvement. Foreign direct investment impact on GEE is not significant, but green credit has a significant positive coefficient. (3) From a regional perspective, the effects of fiscal decentralization on the green economic efficiency of western region were not significant, but the sign of coefficient found to be negative. However, in the other two regions, fiscal decentralization has a significant positive impact on GEE. Moreover, environmental regulation impact on GEE is positive in eastern region and negative in western part, and not significant in the central region; economic development can promote GEE in the central region and negative in west, but not significant in eastern region. Foreign direct investment (FDI) shows no significant impact in the eastern region but exists a significant negative impact in the other two regions. Finally, green credit has no significant impact in the central region but exists significant positive effect in the other two regions. This paper studies the green economic efficiency of undesired output, which is of great significance to my country's future green development and the formulation of environmental regulation policies.

Keywords Fiscal decentralization · Environmental regulation · GEE · Regions

Introduction

With the progress of human civilization and science and technology, the increasingly advanced process of industrialization has caused multiple symptoms such as environmental pollution, ecological degradation and abnormal climate to continue to invade our living environment. In order to make the bright dawn of human civilization continue forever, people of insight around the world are struggling to find ways to alleviate the ecological crisis. In 1987, the World Council for Environment and Development (WCED) pointed out in the article "A Common Future" that the goal of developing human civilization should be to meet the economic development needs of the current people without destroying the development needs of future generations. The point of view later became the cornerstone of sustainable development theory. In the 1990s, the United Nations held a meeting in Rio, Brazil, to discuss issues related to the environment and economy and formulated and issued important documents such as Agenda 21, which aimed to further call on countries around the world to pay attention to environmental dilemmas and continue to strengthen environmental governance. In 2008, the Global Green Economy Initiative and Green New Deal were launched at the United Nations Climate Change Conference. In the following years, major economies in the world have formulated and introduced corresponding countermeasures, making efforts to avoid the dilemma of the

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global ecological environment and achieve green, sustainable and efficient development.

China relied more on the massive input and expansion of production factors to support rapid economic growth (Hansen et al. 2018); it may be hinder the sustainable development of the economy. Nowadays, Chinese economy is facing the bottleneck of resources and environment internally (Jabbour et al. 2020; Umar et al. 2020). Chinese economic transformation is imperative. Chinese 14th Five-Year Plan put forward: "Promoting the advanced industrial base, improving economic quality, efficiency and core competitiveness, promoting economic and social development green transformation." GEE has become the focus of academic and government attention. GEE is the economic efficiency value that comprehensively considers the input of resource elements and the output of environmental pollution. It needs to summarize the changing trend of GEE in Chinese cities, analyze the differences in GEE between regions, pay attention to the factors affecting green economic efficiency, and explore how to improve green economic efficiency and narrow the efficiency gap between regions. It is particularly urgent and important (Lin and Tan 2019).

The development of a green economy is inseparable from the regulation of the government, and the role of the government in the development of the green economy is self-evident. Therefore, while promoting high-quality economic development, we must pay attention to the reform of the fiscal decentralization system. The development of green economy is gradually shifting from the national concept to the stage of government practice, and the fiscal and taxation policies of local governments play an important role in green economy (Ali et al. 2021; Mikhno et al. 2021). China's tax system reform has created a huge financial gap, which has caused increased financial pressure on local governments. In the face of huge financial pressure, local governments have both intensified tax collection and management or expanded tax sources and selected industrial enterprises that can bring local exclusive tax sources. To achieve the goal of increasing taxes to promote local economic development (Zheng and Zhou 2021), local governments will attract capital inflows by providing tax incentives, infrastructure construction, and relaxing environmental rules, thus forming competition. In the process of competition, local governments tend to introduce high output and quick results for short-term economic interests and invest more limited financial funds in infrastructure construction with short cycles and quick results, and other productive fields, even at the cost of relaxing environmental rules to attract investment and develop the economy at the expense of the environment (Jain et al. 2021; Khan et al. 2021). These short-sighted behaviors will undoubtedly reduce the expenditure on public goods such as environmental governance, make the development of local public utilities lag behind economic construction, aggravate environmental pollution, and affect GEE. In this context, analyzing local government competition behavior impact on GEE with fiscal decentralization, and examining the relationship between fiscal decentralization and GEE, can not only gain a deeper understanding of the characteristics of local government competition behavior, but also give targeted policy suggestions for optimizing the current fiscal decentralization system (Kassouri 2022).

Nowadays, the ecological civilization has achieved remarkable results (Wang and Li 2021), but it cannot be ignored that China's environmental protection situation is still severe at this stage. Environmental regulation has now become the main means for the government to control environmental pollution. First, with the upgrading of environmental regulations, enterprises will reduce production costs through technological innovation, thus verifying the "Porter Hypothesis" (Ranocchia and Lambertini 2021). Second, environmental regulation increases the initial production cost of enterprises and squeezes the funds used by enterprises for independent research and development, thus inhibiting GEE. Therefore, does environmental regulation play a moderating role in industrial transfer impact on GEE? Does government environmental regulation upgrade prompt enterprises to carry out technological innovation to improve GEE? Or lead to the gradient transfer of polluting industries, resulting in a "pollution shelter" effect? To comprehensively assess the aforenoted issues, present study has been designed.

The main contributions of this paper are as follows: (1) The model considering undesired output is chosen to measure China's GEE. (2) The existing research has carried out a lot of research on regional differences, but the research mainly focuses on the differences in GEE. However, there are very few studies on the impact of fiscal decentralization on the efficiency of green economy in different regions. The research based on this is a useful supplement to the existing research. (3) It provides targeted policy suggestions for China to improve GEE. It is of great significance to improve the GEE.

Literature review

Fiscal decentralization and GEE

At present, research on these areas can basically be summarized into the following two views: (1) Fiscal decentralization is beneficial to environmental protection and pollution control. Tiebout (1956) pointed out that fiscal decentralization could help governments provide public goods such as a better environment. Oates (1972) believed that fiscal decentralization is more conducive to the local government's construction of public utilities such as environmental

governance. (2) Fiscal decentralization may intensify competition among local governments, leading to local governments lowering pollution standards for more investment, which in turn exacerbates environmental degradation. As a result, fiscal decentralization deepens environmental pollution. Weingast (1997) believes that fiscal decentralization may intensify competition among local governments, which may lead to local governments making improper decisions in pursuit of their own interests, leading to local governments lowering pollution standards to attract regional investment and improving regional economic levels. On the one hand, it also aggravated the environmental pollution, and the final result was that the fiscal decentralization deepened the environmental pollution in the region. Cumberland (1981) pointed out that in order to improve economic development, local governments will lower the environmental threshold and attract many foreign enterprises entering the regions for investment and production. This inter-regional competition that only pays attention to the economy and ignores the environment will inevitably increasing environmental pollution. Kunce and Shogren (2007) found that governments will relax environmental protection standards, thereby increasing environmental pollution in a region.

Domestic research on this area is relatively late. Huang et al. (2012) believe that due to unclear property rights in China, local governments will compete with each other under political and economic incentives, resulting in a decline in regional environmental governance. Second, tax competition may lead "race to the bottom" phenomenon in environmental governance. Li and Liu (2013) studied inter-regional government tax competition impact on environmental governance, and the results showed that the "bad competition" of environmental policies led to the reduction of environmental quality. In addition, Zheng et al. (2018) based on the neoclassical framework, believed that fiscal decentralization hindered environmental pollution. However, He et al. (2018) thought that the greater financial decentralization, the more sufficient the financial expenditures will be, and the more they can meet the needs of environmental governance. In the absence of obvious inter-regional competition, fiscal decentralization is beneficial to environment. Wu and Peng (2014) calculated the GEE after excluding external influences. The results found that the improvement of the two factors of fiscal decentralization and transfer payment is conducive to improve GEE. Bu (2017) concluded that fiscal decentralization can improve GEE.

Environmental regulation and GEE

Some scholars believed that environmental regulation hinder GEE. Sinn (2008) proposed the "green paradox," arguing that environmental protection measures aimed at improving climate problems will lead to accelerate the use of fossil energy. Schou (2002) believes that with the exhaustion of fossil energy, the available resources will also decrease, which will force GEE improvement. Therefore, in the long run, environmental improvement is an inevitable phenomenon, rather than the role of environmental policy. Gray (1987) believed that under the premise of technical conditions, resource allocation and market demand, the enterprise has reached the optimal production, and the environmental regulation policy will cause the enterprise to pay extra costs for environmental governance. Crowding the productive investment of enterprises reduces the innovation ability and market competitiveness of enterprises. Richard and Edward (2012) stated that innovation activities have the characteristics of high cost and high risk, so most enterprises often prefer to reduce R&D investment to make up for pollution control expenditures. In addition, government environmental regulations also require enterprises to purchase corresponding pollution control equipment and technologies to reduce pollution emissions and meet mandatory production standards, which will inevitably increase the cost burden of enterprises and hinder their green technology upgrades (Xing and Kolstad 2002). When the regulatory standards are high, polluting enterprises will also take the initiative to evacuate and continue production in areas with looser environmental policies to reduce pollution costs and maintain market competitiveness (List and Co 2000). Domestic scholars (Xie and Ren (2007)) analyzed from the industrial level and believed that China's environmental is still lower level and under the constraints of environmental regulations, the increase in production costs will further reduce its environmental and economic efficiency. Tao et al. (2018) proved that environmental regulation separated from energy structure upgrade cannot improve economic efficiency by constructing a PSTR panel smooth transfer model. Zhou (2007) pointed out that under the performance appraisal system, the blind pursuit of economic interests by local officials will aggravate local environmental pollution, which is the "pollution shelter effect" that weakens the effectiveness of government environmental regulation through pollution transfer.

However, some scholars thought environmental regulation will not reduce the production efficiency. To ultimately achieve the purpose of improving the productivity and competitiveness of enterprises (Porter and Linde 1995). The empirical analysis of Berman and Bui (2001) also verified Porter's point of view, that is, environmental regulation can improve environmental productivity of regulated enterprises. Zhou et al. (2013) believe that environmental regulations require enterprises to invest in pollution treatment technologies and collect sewage charges, which can significantly improve China's energy environmental efficiency. Silvia et al. (2017) took industries and enterprises in OECD countries as research objects and empirically found that for technologically advanced industries and enterprises,

environmental regulation is more helpful to improve their production efficiency. Du and Li (2019) and Boyd and Pang (2000) found that environmental regulation could reduce the emission of pollutants. Domestic scholars (You and Deng (2019)) took market-based environmental regulation as a research perspective and found that under environmental regulation, enterprises cleaner production motivation has been greatly improved. Xiao et al. (2020) took 11 resource-based industries as research objects and empirically found that environmental regulation can significantly improve GEE. Liu et al. (2020) studied from the industrial level and proved that environmental regulation improves the total factor productivity.

Furthermore, few studies have shown that the relationship is uncertain. Wu and Zhang (2018) empirically found that only in areas with moderate intensity, environmental regulation could improve green total factor productivity. Huang and Gao (2016) also found obvious regional characteristics between them. Li and Li (2021) took the policy of "two control areas" as an example and found that environmental regulation could increase industrial output value, but its effect is heterogeneous in different regions. Yin (2012) found that when the environmental regulation began to increase, foreign direct investment hindered the GEE. The effect is transformed into a promoting effect. Chen et al. (2018) found that environmental regulation has an effect of promoting GEE first and then inhibiting it, showing an "inverted U-shaped" curve relationship. Zhang et al. (2018) found that environmental regulation increasing would turn the promotion effect of foreign capital inflow on GEE into a hindrance effect. Qiao et al. (2020) found that green taxation shown a changing relationship of promotion first and then inhibition. Zhang and Chen (2020) decomposed green productivity into green technological progress and technical efficiency and found that informal environmental regulation can improve green productivity through green technological progress and technological efficiency, but formal environmental regulation inhibits the growth of green technology efficiency.

Through literature review, it is known that there are many related studies on GEE measurement. Green economic efficiency is mainly measured by data envelopment analysis. Although relevant research has been quite abundant, few people have incorporated environmental regulation and fiscal decentralization into a unified framework to explore the impact on GEE. At the same time, the existing research ignores that environmental regulation impact on GEE may vary greatly due to factors such as the geographical location and development level of different cities, which can easily lead to deviations. Therefore, considering region particularity, the study selects 30 regions as the research objects to explore the regional differences. This study will construct a theoretical analysis framework between fiscal decentralization, environmental regulation, and GEE, measure GEE and use Tobit model to explore the relationship between them, providing a theoretical basis for the government to rationally formulate environmental policies, plan fiscal decentralization, and promote GEE development.

Methods

Data envelope analysis (DEA)

Model development

When measuring production efficiency, Pittman (1983) found that ignoring undesired outputs such as environmental pollution may lead to a certain bias in the evaluation of production efficiency, so Pittman (1983) incorporates environmental factors into production efficiency measurement, and improved the super logarithmic productivity index. Green economic efficiency is a comprehensive efficiency measurement index, which needs to consider economic factors and environmental costs when measuring efficiency. The traditional DEA model is one of the most widely used. However, traditional DEA models are mostly evaluated based on the measurement method of radial angle, without considering the undesired output value, the slackness and redundancy might lead to deviations, and cannot truly reflect the actual efficiency on certain limitations. In 2004, Tone proposed the SBM (slacks-based measure) efficiency evaluation model, which introduced slack variables of input and output, and constructed a measurement model based on slack variables considering undesired output, which guaranteed the results of the calculation. However, when the SBM-DEA model measures efficiency, multiple decision-making units may be effective which cannot comparative analysis of specific results. Tone and Tsutsui (2010) improved and developed the SBM model and put out super-SBM model, which was able to compare different effective decision units. The study uses super-efficiency SBM method, referring research of Zhou and Nie (2012), and constructs the following model to measure GEE:

Suppose there are decision-making units, and each decision-making unit contains three vectors: input, expected output, and undesired output, respectively representing $x \in R^m, y^g \in R^{s1}, y^b \in R^{s2}$, which is defined as three matrices X、Y^g, Y^b as follows:

$$X = \left[x_1, x_2, \cdots x_n\right] \in R^{m \times n} \tag{1}$$

$$Y^g = \left[y_1^g, y_2^g, \cdots y_n^g\right] \in R^{s1 \times n} \tag{2}$$

$$Y^b = \left[y_1^b, y_2^b, \cdots y_n^b\right] \in R^{s2 \times n} \tag{3}$$

Among, $X > 0, y^g > 0, Y^b > 0$, then the production possibility set can be expressed as

$$p = \left\{ \left(x, y^g, y^b \right) | x \geq \lambda x, \lambda y^g, y^b \geq \lambda y^b, \lambda \geq 0 \right\} \quad (4)$$

The super-SBM model can be expressed as

$$\rho^* = \min\rho = \frac{\frac{1}{m}\sum_{i=1}^{m} \frac{\overline{x_i}}{x_{i0}}}{\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s1} \frac{\overline{y_r^g}}{y_{r0}^g} \right) + \left(\sum_{r=1}^{s2} \frac{\overline{y_r^b}}{y_{r0}^b} \right)} \quad (5)$$

$$\text{Constraints(s.t)} : \overline{x} \geq \sum_{i=1,\neq 0}^{n} \lambda_i x_i \quad (6)$$

$$\overline{y^g} \leq \sum_{i=1,\neq 0}^{n} \lambda_i \overline{y_i^g} \quad (7)$$

$$\overline{y^b} \leq \sum_{i=1,\neq 0}^{n} \lambda_i \overline{y_i^b} \quad (8)$$

Among $\overline{x} \geq x_0, \overline{y^g} \leq y_0^g, \overline{y^b} \geq y_0^g, \lambda > 0$, the letters in the formula are the same as the above formula, and the larger $\rho*$ means more efficient.

Variable selection

This paper refers to the construction of the evaluation index system by scholars such as Qian and Liu (2013); Liu et al. (2017), with the conceptual connotation of GEE and the availability of data, select 2008–2020 provincial-level data; the following evaluation index system was constructed. In terms of input variables, according to the CD production function, energy investment consumption is essential in the production activities of enterprises. Therefore, the input indicators include below three inputs.

(1) *Labor input*: According to the research of domestic scholars (Che et al. 2018; Wang and Wei 2016), the labor input index uses employees in each region, and no further processing is required.
(2) *Capital investment*: Most scholars use capital stock to represent the factors of capital investment. Referring to the practice of Shan (2008), with 2008 as the price base period, the investment amount of fixed assets in each region over the years is converted according to the perpetual inventory method. It is calculated as

$$K_i = K_{i-1} \times \left(1 - D_i\right) + I_i \quad (9)$$

Among them, K_i represents the capital stock in the i period, D_i is depreciation rate, and I_i is investment in fixed assets. The depreciation rate is 10.96%.

(3) *Energy input*: China is a big country of energy consumption, and energy consumption has an important impact on GEE. Referring to existing research results, this study uses the total energy consumption to represent (Yang and Hu 2010). The data comes from China Industrial Statistics Yearbook.
(4) *Expected output*: The development of GEE is related to economic development. This article refers to existing research. The actual GDP of each province after deflating the GDP price index in 2008 as the base period represents the expected output level.
(5) *Undesirable output*: The study selects the total amount of industrial wastewater discharge, total industrial waste gas discharge, and total industrial solid waste discharge to measure the undesired output in green economic efficiency see Table 1.

Tobit model

Model formulation

Considering that GEE is a limited explained variable, the study chooses s a Tobit model to verify the relationship between variables. Since the explained variable of GEE and its data is distributed between 0 and 2, which is discrete, the Tobit model is used to explore the correlation between GEE and influencing factors. The basic form of the model as below:

$$\begin{cases} y_{it}^* = X_{it}\beta + Z_{it}\beta_1 + \mu_1 + \varepsilon_{it} \\ y_{it} = max\left(0, y_{it}\right) \end{cases} \quad (10)$$

In the model, y_{it}^* 、 y_{it} 、 X_{it}, and Z_{it} represent the explained variable matrix, the observed explained variable

Table 1 Indicator system

Indicator	Mean	Standard deviation	Minimum	Maximum
Labor input	2452.345	4124.231	91.341	42,158.982
Capital input	43,872.632	18,499.032	24,092.093	98,763.821
Energy input	533,421.231	783,211.432	3432.452	4,456,821.232
Regional real GDP	649,290.4762	567,532.033	314,045.43	1,015,986.000
Industrial waste gas emissions	2067.432	2234.124	98.532	21,321.123
Industrial wastewater discharge	312,780.912	145,679.612	478.096	2,096,782.863
Industrial solid waste discharge	43,479.119	134,571.912	789.143	3,123,569.221

matrix, the explanatory variable matrix, and the control variable matrix in turn. The maximum likelihood estimation of the model parameters can be expressed as follows:

$$\hat{\theta} = arg\max_{\theta} \sum_{i=1}^{n} \left(1 - I_{(0,\infty)}\left(y_{it}\right)\right) ln\left(L_{it}^{1}\right) + \max_{\theta} \sum_{i=1}^{n} \left(1 - I_{(0,\infty)}\left(y_{it}\right)\right) ln\left(L_{it}^{2}\right) \tag{11}$$

$$\theta_t = \left(\beta_i, \gamma_i, \sigma_i\right), L_{it}^{1} = \varphi\left(\frac{-\left(X_{it}\beta + \overline{X}_i Y\right)}{\sigma_i}\right), L_{it}^{2} = \frac{1}{\sigma_t}\varphi\left(\frac{-\left(X_{it}\beta + \overline{X}_i Y\right)}{\sigma_i}\right) \tag{12}$$

$$I_{(0,\infty)} = \begin{cases} 1 \ if \ y_{it} \geq 0 \\ 0 \ if \ y_{it} < 0 \end{cases} \tag{13}$$

Variable selection

(1) Dependent variable

Green economic efficiency (GEE): Select the results calculated by the DEA model.

(2) Explanatory variables

Fiscal decentralization (FENQ). On the one hand, the central government's assessment mechanism can promote the government to actively use fiscal expenditures to optimize regional resources through strategies such as building urban infrastructure, introducing high-quality foreign capital, guiding capital inflows, increasing investment in scientific and technological innovation, and attaching importance to the cultivation of regional talents. Allocation promotes regional economic development, which is reflected in the promotion of green economic efficiency. On the other hand, decentralization of financial power will give local governments the power to increase spending. The increase in power will lead to competition among local governments, resulting in an unreasonable structure of government spending. For example, government spending does not pay attention to the construction of public goods and repeated infrastructure construction. These factors will have a negative impact on the efficiency of the green economy. Therefore, the impact of fiscal decentralization on the efficiency of green economy is affected by the optimal allocation of resources and the distortion of government behavior. Ultimately, the promotion or inhibition is the result of a comprehensive battle between these two aspects. Therefore, it is necessary to explore the impact of fiscal decentralization on regional green economic efficiency. There are mainly including three categories to represent: (1) FENQ = local fiscal expenditure/central level (or expenditure within the national fiscal budget); (2) FENQ = local fiscal revenue/central level (or revenue within the national budget); and (3) the degree of fiscal autonomy (that is, the proportion of proportion of expenditure at the same level) budgetary revenue/total budgetary expenditure(Fang et al. 2019). The study selects the ratio of the province's general public budget revenue divided by the general public budget expenditure to measure the degree of fiscal decentralization.

Environmental regulation (ER). GEE is inseparable from the protection and governance of the environment. The greater the intensity of environmental regulation, the less pollutant emissions from undesired outputs and the more effective the improvement of GEE. But environmental regulation may also affect the output value of industrial production, leading to GEE decrease (Wang and Sun 2019). Domestic and foreign indicators of environmental regulation are often measured by pollution control investment, pollution income, or the proportion of pollution fees in taxes. Considering the availability of panel data, the income from pollution discharge fees is selected to represent.

(4) Control variables

Foreign direct investment (FDI). FDI have an impact on the local GEE, mainly including the technology diffusion effect of introducing foreign advanced technologies and the "pollution paradise" hypothesis of foreign companies transferring low value-added industries (Chen et al. 2020). The ratio of the current year's exchange rate to the RMB price and the year's GDP represents the degree of FDI.

Economic development (GDP). The economic development level of a region reflects the development scale and economic strength of the city. Generally speaking, economically developed cities spend more to improve ecological environment, which is of great help to GEE development (Nie and Wen 2015), so as to eliminate the price factor, the real GDP per capita is used to measure the economic development level of the region, and the logarithm of GDP per capita is taken.

Green credit (GF). The green development requirements make green economic efficiency require green credit as a financial tool (Xie and Liu 2019). Therefore, the study selects the proportion of interest expenditures of six energy-intensive industries, the reverse indicator of green credit, to measure green credit to reflect the bank's efforts to curb environmental deterioration. In order to facilitate the interpretation of the empirical results, "(1) the proportion of interest expenditures of the six energy-intensive industries" is finally used as the proxy index of the green credit indicator, which is expressed as the proportion of green credit.

Urbanization (UL). In the process of urbanization promotion, while stimulating fiscal expansion and economic growth, the accompanying issues such as ecology, environmental protection, and pollution have also attracted the attention of the public. This study chooses to measure the level of urbanization by the ratio of urban population to the total population at the end of the year (Fan and Zhang 2022).

The Tobit model as below:

$$GEE_{it} = \alpha_0 + \alpha_1 FENQ_{it} + \alpha_2 ER_{it} + \alpha_3 GDP_{it} + \alpha_4 FDI_{it} + \alpha_5 GF_{it} + \alpha_6 UL_{it} + \mu_{it} \quad (14)$$

Among them, GEF_{it} is regional green economic efficiency; $FENQ_{it}$、ER_{it}、GDP_{it}、FDI_{it}、GF_{it}, and UL_{it} represent fiscal decentralization, environmental regulation, economic development level, FDI, green credit, and urbanization; α_1 to α_6 are the regression coefficients of each variable; i is each region; t is the year; and μ_{it} is the random error.

Results

Calculation results of China's regional GEE

According to the results of variable selection, get the results as follows (Table 2), and the change trend of the national average GEE is plotted in Fig. 1.

From Table 2 and Fig. 1, it can be found that China's average GEE is at an upper-middle level, and the green economic efficiency varies greatly among provinces and cities, reflecting China's vast territory and the large differences in its own conditions and development status in different regions. Among them, Beijing, Shanghai, Jiangsu, and Zhejiang have high levels of green economic efficiency, with an average value greater than 1, and are at the forefront of green development. However, the GEE values of Ningxia, Qinghai, Xinjiang, and Gansu are lower than 0.4.

For the purpose of observing the differences of GEE values in different regions, this paper calculates the annual average of GEE in whole China and the three major regions of eastern, central, and western regions. The value of eastern is 0.991, central is o.734, and western region is only 0.467, which is relatively lower. Because the eastern economic development has always been at a leading level, both the supply of developing funds and the ability to introduce various advanced technologies and talents are more advantageous than other regions. At the same time, the eastern region can also enjoy the latest preferential policies and benefits and will be more responsive to environmental protection and reduce pollution emissions. The GEE of the central region is also above the national average level, which is also related to the economic development level. In the process of catching up with the high level in the eastern region, the economic growth rate of the central region is also rising, and the pace of industrial development is accelerating. This leads to increased pollution and excessive consumption of resources. The GEE of the western region is lowest; on the one hand, due to the special geographical environment and harsh climate in the western region, the population density is low, the population scale efficiency is lacking, and the population economic endowment is not as good as the other two regions. The inconvenience of its transportation also restricts economic growth; on the other hand, the national policy is inclined later, and the culture and technology are relatively backward. Regarding the spatial differences in green economic efficiency, the research in this paper is consistent with that of previous scholars. For example, scholars Yu and Jiang (2017) concluded that the level of green economic efficiency is on the rise, but the development of green economy is unbalanced between regions, and the green economic efficiency is high in the east. It is low in the west, decreasing from east to west, and the development of green economy in various regions is not perfect; scholars Qian and Liu (2013) also came to the same conclusion.

Tobit model regression results and analysis

Variable descriptive statistics

This paper uses Stata14.0 measurement software to conduct empirical analysis. Table 3 is descriptive statistics. From Table 3, the average level of GEE in China from 2008 to 2020 is moderate. The average value of the explained variable GEE in the model is about 0.7300, and the maximum value is 7.74 times the minimum value. There are large differences in efficiency, and there are large differences in environmental regulation and fiscal decentralization between regions, so it is necessary to study the regional differences.

Multicollinearity test for variables

Before the study, we tested the collinearity of each variable and calculated the variance inflation factor VIF value of each explanatory variable (as shown in Table 4). The VIF value of each variable is less than 10, indicating that there is no multicollinearity problem between variables..

Variable stationarity test

Before doing regression analysis, needs to do a data stability test, the study uses LLC method to test, results as Table 5. It can be finding from Table 4 that the model variables reject the null hypothesis, and all variables are stationary in the same order.

In Table 5, all variables are all steady. Therefore, further regression analysis can be carried out.

Table 2 China's regional GEE

	Region	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Mean
Eastern	Beijing	1.691	1.731	1.765	1.832	1.784	1.932	2.143	2.265	2.326	2.484	2.502	2.951	3.165	2.198
	Tianjin	0.564	0.577	0.612	0.635	0.696	0.707	0.729	0.743	0.784	0.807	0.831	0.857	0.923	0.728
	Hainan	0.514	0.522	0.546	0.614	0.637	0.665	0.709	0.733	0.784	0.824	0.843	0.886	0.951	0.710
	Hebei	0.511	0.543	0.633	0.667	0.699	0.711	0.715	0.716	0.744	0.823	0.846	0.874	0.813	0.715
	Liaoning	0.422	0.427	0.529	0.534	0.567	0.647	0.702	0.759	0.761	0.769	0.815	0.881	0.911	0.671
	Shandong	0.513	0.533	0.643	0.677	0.685	0.722	0.725	0.736	0.741	0.812	0.824	0.874	0.813	0.715
	Shanghai	0.833	0.845	0.912	0.945	0.966	1.021	1.063	1.368	1.415	1.474	1.516	1.609	1.732	1.208
	Jiangsu	0.802	0.815	0.825	0.829	0.847	0.994	1.067	1.178	1.189	1.191	1.232	1.326	1.482	1.060
	Fujian	0.82	0.832	0.838	0.843	0.856	0.858	0.859	0.864	0.867	0.877	0.886	0.912	0.933	0.865
	Zhejiang	0.722	0.765	0.845	0.866	0.907	0.934	1.005	1.145	1.178	1.198	1.212	1.436	1.586	1.061
	Guangdong	0.729	0.736	0.738	0.746	0.838	0.871	0.882	0.887	0.897	0.972	1.228	1.355	1.667	0.965
Western	Gansu	0.191	0.196	0.219	0.328	0.369	0.376	0.415	0.427	0.429	0.435	0.438	0.443	0.448	0.363
	Chongqing	0.523	0.533	0.536	0.54	0.551	0.561	0.572	0.578	0.58	0.586	0.591	0.611	0.615	0.567
	Sichuan	0.513	0.545	0.559	0.565	0.568	0.578	0.583	0.591	0.595	0.607	0.614	0.617	0.623	0.581
	Shaanxi	0.513	0.519	0.527	0.536	0.539	0.549	0.554	0.556	0.558	0.565	0.569	0.633	0.649	0.559
	Yunnan	0.524	0.532	0.535	0.538	0.541	0.542	0.599	0.616	0.613	0.628	0.631	0.639	0.643	0.583
	Guizhou	0.366	0.386	0.392	0.412	0.429	0.435	0.445	0.449	0.451	0.453	0.455	0.357	0.464	0.423
	Qinghai	0.281	0.282	0.384	0.286	0.319	0.324	0.331	0.342	0.346	0.353	0.356	0.389	0.424	0.340
	Neimenggu	0.521	0.604	0.605	0.613	0.618	0.621	0.623	0.629	0.631	0.64	0.647	0.656	0.667	0.621
	Guangxi	0.371	0.375	0.378	0.421	0.427	0.429	0.421	0.434	0.439	0.449	0.459	0.483	0.492	0.429
	Ningxia	0.217	0.225	0.249	0.251	0.255	0.258	0.269	0.271	0.275	0.287	0.371	0.374	0.391	0.284
	Xinjiang	0.315	0.336	0.345	0.389	0.391	0.392	0.396	0.396	0.397	0.403	0.42	0.435	0.442	0.389
Central	Shanxi	0.642	0.633	0.637	0.646	0.648	0.658	0.767	0.769	0.812	0.821	0.782	0.735	0.831	0.722
	Henan	0.603	0.605	0.611	0.615	0.621	0.623	0.624	0.638	0.642	0.646	0.649	0.651	0.652	0.629
	Jilin	0.632	0.645	0.654	0.666	0.667	0.672	0.773	0.811	0.782	0.826	0.843	0.876	0.879	0.748
	Hunan	0.721	0.723	0.725	0.736	0.738	0.741	0.746	0.751	0.756	0.757	0.759	0.761	0.762	0.744
	Heilongjiang	0.645	0.655	0.667	0.669	0.677	0.679	0.733	0.781	0.783	0.825	0.867	0.878	0.889	0.750
	Hubei	0.603	0.611	0.615	0.619	0.629	0.631	0.635	0.647	0.635	0.648	0.655	0.657	0.659	0.634
	Jiangxi	0.711	0.713	0.732	0.815	0.847	0.868	0.877	0.889	0.899	0.909	1.013	1.025	1.026	0.871
	Anhui	0.731	0.735	0.739	0.738	0.732	0.743	0.752	0.766	0.771	0.798	0.819	0.843	0.858	0.771
National mean		0.591	0.606	0.633	0.652	0.668	0.691	0.724	0.758	0.769	0.796	0.822	0.867	0.913	0.730

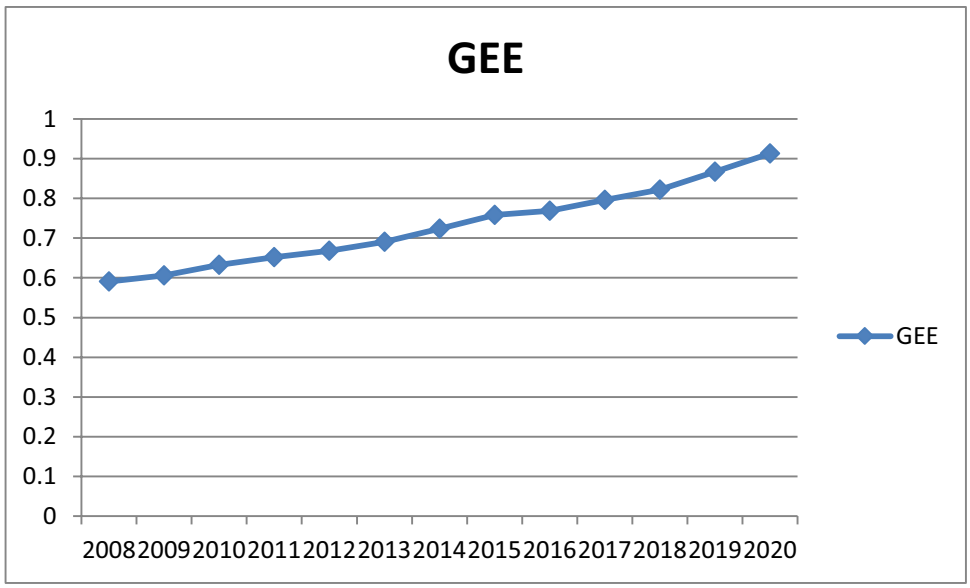

Fig. 1 Trend of average GEE in China

Table 3 Descriptive statistics

Variable	Sample size	Mean	Standard deviation	Minimum	Maximum
GEE	390	0.7300	0.2123	0.191	3.165
FENQ	390	0.4422	0.0988	0.0123	0.9653
ER	390	0.2433	0.4509	0.0032	3.7732
GDP	390	24,998.093	14,773.53	78.372	11,092.46
FDI	390	0.0493	0.0122	0.0003	0.1209
GF	390	0.4653	0.1322	0.1114	0.7842
UL	390	0.5233	0.134	0.2034	0.9483

Table 4 Multicollinearity test results

Variable	GEE	FENQ	GDP	FDI	GF	UL
VIF	1.22	2.36	2.37	3.49	4.78	3.12

Table 5 Result of stationarity

Variable	LLC statistic	*p* value	Test result
GEE	−17.092	0.0000	Steady
FENQ	−22.2352	0.0000	Steady
ER	−10.1231	0.0000	Steady
GDP	−4.6674	0.0412	Steady
FDI	−17.8975	0.0000	Steady
GF	−10.2136	0.0104	Steady
UL	−3.5988	0.0001	Steady

Table 6 Tobit regression results

Variable	National	East	Central	West
FENQ	−0.1343***	0.0435***	0.1329***	−0.0056
	(−4.01)	(3.11)	(2.99)	(−1.23)
ER	−0.2066**	0.0482***	0.1351	−0.0322***
	(−2.01)	(5.43)	(0.88)	(−3.08)
GDP	−0.1123**	0.0211	0.1543***	−0.1315***
	(−1.98)	(0.99)	(5.67)	(−4.36)
FDI	0.0455	0.1093	−0.1324*	−0.2221***
	(1.21)	(0.94)	(−1.76)	(−4.04)
GF	0.2341***	0.2461***	0.0513	0.1004***
	(6.88)	(5.28)	(1.02)	(5.44)
UL	−0.0133*	−0.0655*	−0.0604	−0.0032
	(−1.87)	(−1.69)	(−0.76)	(−0.69)
-cons	0.1109***	0.3098***	−0.6799***	0.3876
	(7.44)	(7.21)	(−6.42)	(1.27)
Hausman	$p=0.6567$	$p=0.9344$	$p=0.6766$	$p=0.9932$

*** means $p<0.01$, ** means $p<0.05$, * means $p<0.1$; t value in parentheses

Tobit regression results

Substitute the data into the Stata software and results as follows Table 6. The Hausman test found that the *p* value was not significant, so the study selects random effect model.

(1) National level

The effect of fiscal decentralization on GEE is significant, and the coefficient is negative, that is, the fiscal decentralization inhibits the GEE in the region. It shows that local governments sacrifice the environment for regional economic benefits, so fiscal decentralization hinder the improvement of GEE, which is consistent with the conclusions drawn by some scholars. For example, Luo and Wang (2017) found that the financial situation of local governments is relatively optimistic and their economic autonomy is strong. Local governments are more willing to develop economy under their own interests and existing incentive systems, while ignoring the improvement of environmental quality.

There is a significant negative between environmental regulation and GEE, meaning that the stricter of environmental regulation, the more unfavorable to economic growth, thus inhibiting the improvement of local green economic efficiency and verifying the "investment crowding out effect" brought about by the "following cost effect" mentioned above, which is in line with the current environmental regulation in my country pointed out by Li (2019). The conclusion that the "innovative compensation effect" cannot compensate for the pollution control cost brought by environmental regulation is relatively consistent. FDI is not significant impact on GEE; this is inconsistent with the research conclusions of some scholars. Li and Liu (2018) concluded that it is not conducive to the improvement of green economic efficiency. He believes that this may be due to the unreasonable structure of my country's import and export trade, the low added value of export products, and most of them are processing trade. The consumption of resources and the environment is relatively large. This paper concludes that this negative effect is not significant. The possible reason is that the data used in this paper is relatively new, and the quality of China's foreign direct

investment has been significantly improved, so the negative effect on green economic efficiency is not significant. There is an inverse relationship between GDP per capita and GEE, it shows that only high-quality economic growth can promote the improvement of GEE, and some scholars have also concluded that there is a "U"-shaped nonlinear relationship between the level of economic development and the efficiency of green economy (Han 2019). Green credit has a significant positive impact on GEE. This is because the expansion of green credit scale allows funds to be more focused on green development areas, resulting in economies of scale and improved production efficiency. On the one hand, green credit promotes the growth of economic scale through capital accumulation, and there is a positive effect on resource utilization and the environment due to its green environmental protection attributes and contributes to the improvement of GEE. On the other hand, green credit has given full play to its role in effectively allocating resources and financing funds and using funds more rationally in various fields. This test result supports the previous theoretical analysis and also provides an empirical basis for the possible positive effects of green credit introduced by China's banking industry on green development. China's green credit can meet the inherent needs of green development; this is consistent with the conclusions of some university scholars (Zhu Guangyin, Wang Simin, 20,322; Cheng Siwei, 2012). Urbanization rate impact on GEE is negative, meaning that the excessive expansion brought about by urbanization cannot improve GEE; this is inconsistent with the conclusions drawn by some scholars. For example, scholar Wang (2019) concluded that there is a positive correlation, but it did not pass the significance test. The possible reason is that although the urbanization process will carry the flow of elements, it has a negative impact on certain factors. The role of regional green development occurs in stages: in the early stage of urbanization, population mobility will exacerbate the contradiction between human and resource supply and the carrying capacity of the environment. Intensifying environmental pollution, the influx of factors brought by it and the negative impact on the society and the people's livelihood and the ecological environment offset each other; as urbanization enters a stable period, the scale effect will gradually emerge.

(2) Regional level

Fiscal decentralization impact on GEE in the eastern and central regions is significant, and the coefficient is positive, means fiscal decentralization has been transformed into a driving force. Encourage local governments to expand tax sources, strive to find new fiscal revenue, and promote the development of GEE in these two regions while economic growth (Fang and Zhang 2014). Although this result in the western region did not pass the significant test, but the sign is negative, indicating that greater fiscal decentralization will inhibit GEE improvement. In order to alleviate fiscal decentralization, local governments often choose to develop the secondary industry based on regional resource endowments or carry out industrial transfer mainly based on the secondary industry, neglecting the protection of the environment in the process of environmental protection. There is an urgent need to change the government's economic development mode. Under the huge and continuous fiscal decentralization, local governments will seize the supply-side reform, strive to adjust the economic structure, promote economic growth and protection of the ecological environment, and finally achieve a purpose of improving GEE.

The influence coefficient of environmental regulation on GEE in the east is positive, means it can improve GEE. When environmental regulation higher, and it can greatly improve GEE; the impact in the central is not significant, may be because its lower economic development, so its effect is not significant; but in the west is significant negative, means it will inhibit GEE.

GDP per capita can promote GEE in the central region, indicating that this region pays more attention to environmental restoration while economic development and promotes GEE. In the west of China, existing a negative effect, and low-quality economic development hinder the improvement of GEE, this effect is not significant in the eastern region.

FDI has shown a significant negative impact in the central and western regions. This is basically consistent with the conclusions of Yang and Long (2012) and Li and Fan (2019), but contrary to the conclusions of Yang and Wang (2016) and Zheng et al. (2017). This may be related to the differences in research subjects, research methods, or research indicators selected by the sample. Although foreign investment has brought high and new technology to the local area, the accompanying negative impact cannot be ignored. The gathering place of high-value polluting industries inhibits the improvement of GEE, while the effect in the eastern region is not significant.

Green credit in the eastern region has a significant positive effect on GEE, which shows that increasing the level of green credit in the eastern region of China will help improve GEE. Different regions are located in different geographical locations, have different resources, and accept different policies, which will lead to differences in the development level of different regions. The more developed the economy, the higher the level of understanding and acceptance of policies, so the more developed eastern regions will have more advantages in improving GEE. The green credit in the western region also has a significant positive impact on GEE, but the effect coefficient is low, which means that the green credit has little effect on GEE improvement. It may be due to the low degree of industrialization, which may improve the GEE. However, the economic growth of the western region

is relatively backward, offsetting some of the positive effects. The effect of the central region is not significant, which may be because the positive effect of green credit issuance is offset by the negative effects of other factors in the region itself, such as large population and pollution discharge, and the effect of green credit cannot be shown.

The influence coefficient of urbanization on GEE in the central and western regions is negative but not significant. In the eastern region, urbanization has a significant negative impact on the GEE. Development and energy consumption have significant negative effects on GEE.

Conclusions and applications

Conclusions

This paper constructs a theoretical analysis framework between fiscal decentralization, environmental regulation, and GEE, uses the super-efficiency SBM method to measure GEE, and builds a systematic Tobit model to comprehensively consider the relationship between the three. Conclusions are as follows:

(1) The overall level of GEE in China is in the upper middle range, with Beijing, Shanghai, Jiangsu, and Zhejiang having higher GEE levels, while Ningxia, Qinghai, Xinjiang, and Gansu have lower green economic efficiency values. The GEE varies greatly among regions. The eastern region has the highest GEE value, the western region the lowest, and the central region is between the two, indicating that the level of GEE is closely related to regional economic development.

(2) The impact of fiscal decentralization on the national GEE is significant, and the coefficient is negative, which means that the fiscal decentralization faced by local governments has a negative inhibitory effect on GEE in the region. Environmental regulation has a significant negative impact on GEE, which hinder GEE improvement. FDI has no significant impact on GEE. GDP per capita has a significant impact on GEE, and the coefficient is negative. Green credit has a significant impact on GEE and has a positive coefficient. This is because the expansion of green credit scales makes funds more focused on green development areas, resulting in economies of scale, increasing the productivity. The urbanization excessive expansion brought about by urbanization cannot improve GEE.

(3) Fiscal decentralization in the eastern and central regions can improve GEE, indicating that fiscal decentralization has been transformed into a driving force. Although the result in west of China is negative but not significant, indicating that a larger under the fiscal decentralization, the improvement of GEE will be inhibited; environmental regulation on GEE in the east is positive, meaning that the environmental regulation in the eastern provinces can improve the GEE, and the elasticity coefficient of environmental regulation on the GEE in the central region is positive, but not significant, the coefficient of environmental regulation on GEE in the west is negative, which inhibits regional GEE improvement. The per capita GDP has a significant promoting effect on the GEE in the central region, but it is significantly negative in the western region, and the effect is not significant in the eastern region. Foreign direct investment in the central and western regions shows a significant negative effect, while the effect in the eastern region is not significant. Green credit in the eastern region has a significant positive effect on GEE, and green credit in the western region also has a significant positive impact on GEE, but the effect coefficient is low, and the effect of green credit in the central region is not significant. The influence coefficient of urbanization on GEE in the central and western regions is negative but not significant. In the eastern region, urbanization has a significant negative impact on the GEE.

Suggestions

Based on the above analysis, this paper explores policy measures to improve GEE from the following aspects.

(1) Improve the green economy assessment mechanism and enhance local financial autonomy.

The effective development of a green economy with the characteristics of public goods is not only inseparable from the effective incentive mechanism of the central government, but also requires the specific implementation of the local government. This requires the central government to further incorporate the economy and the environment into the assessment mechanism for local governments, so that local governments will no longer pursue economic growth one-sidedly at the expense of the environment. The government will support the development of local green economy through fiscal and taxation methods and will increase investment in environmental protection and governance to promote local green economy. Continue to advance the reform of the fiscal decentralization system, optimize the proportion of central and local fiscal distribution, and give local governments more flexible fiscal freedom in public services.

(2) Improve the transfer payment system and promote coordinated regional development.

The economic and social development levels of various regions in China are different, and there is also a large gap in GEE. Simply relying on a unified fiscal and taxation system

may affect the efficiency of resource allocation and regional development. Therefore, it is necessary to scientifically design the transfer payment system, balance the financial gap between regions, and improve the ability of each region to meet the spending needs of local residents. At present, China's transfer payment structure is unreasonable. There are many types of general transfer payment projects, diverse objectives, and a weak equalization function. There are many types of special transfer payments, with miscellaneous projects, and the distribution and use are not scientific enough, and the information is not open and transparent enough. Therefore, it needs to improve the transfer payment system, standardize the use of transfer payment funds, strengthen supervision and management, and improve the efficiency of fund use. The central government needs to strengthen transfer payments to areas with weak financial resources. By setting up special funds, it is specially used to support basic public services and infrastructure construction in backward areas, so as to narrow the gap between regions and support the development of economy in backward areas. Only with an economic foundation can innovation, only in this way, can we better manage the environment and realize the green coordinated development of the inter-regional economy.

(3) Adopt a regional differentiation policy.

In view of the regional development differences in GEE, adopt targeted and differentiated policies to improve GEE. For the eastern region, the adjustment of the industrial structure has a certain role in promoting GEE. The rationalization and advanced development of the industrial structure in the eastern region should be carried out to form a complete industrial chain of circular economy. Each city in the central region has its own emphasis on industrial development, forming "specialized" production to improve GEE. In the western region, fiscal decentralization should be slowed down according to local conditions, an appropriate level should be used as a driving force for economic development, and the secondary industry should be the characteristic industry development while ensuring a balanced industrial structure and high-quality development. The central and western regions should form a development situation of harmonious development and healthy competition, and jointly promote GEE.

(4) Formulate scientific environmental regulations.

Local governments should strengthen supervision, moderate intervention, and formulate loose and flexible combined policies, rather than adopting a one-size-fits-all simple method to control environmental pollution, which is not in line with local development. Conditional environmental regulation policies can even have a negative impact on GEE, leading to the creation of pollution shelters as the cost of compliance hypothesis occurs. Specifically, based on eastern region development, the government should focus on green technology development and production technology innovation when formulating environmental regulation policies, strengthening the leading, and radiating role of the eastern developed regions. Environmental regulation policies in the central and western regions should focus on the development and utilization of their own resources and the formulation of thresholds for inflowing enterprises. When undertaking the inflow of foreign and eastern enterprises, the development process should be reasonably controlled, and high-tech manufacturing should be actively introduced to avoid the inflow of seriously polluting manufacturing enterprises, strictly control, and test the inflow enterprises and make reasonable plans for the development of natural resources.

Limitation of this study

(1) This paper lacks a mechanism analysis in analyzing the relationship between fiscal decentralization, environmental regulation, and GEE. It only summarizes the theoretical summary of the existing literature and fails to establish an effective mathematical model to analyze the relationship between the three.

(2) Regarding the research on the relationship between fiscal decentralization, environmental regulation, and green economic efficiency, this paper only starts from the data at the provincial level, and future research can conduct further in-depth research from the data at the industry level.

(3) For the green economy in a broad sense, in addition to realizing economic benefits and ecological environmental benefits in the process of economic development, it is also necessary to realize social benefits. The social benefits here refer to increasing the well-being of human life. Because social benefits cover a wide range and indicators are difficult to quantify, the existing research on GEE mainly starts from the narrow sense of green economy, and the selection of indicators is also mainly from the perspective of economic benefits and resource and environmental benefits. In future research, the quantification of social benefits can be further studied, so that green economic efficiency can comprehensively cover all aspects of the green development process, and the calculation of GEE will be more scientific and accurate.

Author contribution Yancui Han: Conceptualization; methodology; software; data curation; writing, original draft preparation; writing, reviewing and editing; software; visualization; investigation; validation.

Data availability All the data is publicly available and proper sources has been cited in the text.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publications All authors listed are agreed to publish this work.

Competing interests The author declares no competing interests.

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