Impact Assessment and Policy Recommendations of the Green GDP Accounting System on Global Climate Change

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Abstract

As global environmental issues become increasingly pressing, the traditional GDP (Gross Domestic Product) indicator is proving insufficient to comprehensively reflect the sustainability of national economies, particularly in assessing environmental impacts. To address this, the concept of Green GDP (GGDP) has emerged as an alternative economic accounting measure, which incorporates environmental degradation and resource consumption into the national economic accounting system. This study establishes an AHP-CRITIC-CEI integrated model to analyze the feasibility of GGDP reform and examine its impact on global climate change. Firstly, through literature review, four key areas-land use change, agricultural activities, fossil fuel dependence, and aerosol emissions-were selected as primary indicators influencing GGDP accounting, and a comprehensive indicator system was constructed. Using the AHP and CRITIC methods, the weights and composite scores of the indicators were calculated and compared with global heat storage changes to validate the effectiveness of the model. Furthermore, the E-K-means clustering method was employed to classify 44 countries into environmentally friendly, moderate, and environmentally unfriendly categories. The findings revealed that countries adopting GGDP reforms predominantly fell into the environmentally friendly category, suggesting that the transition to GGDP is beneficial for mitigating climate change. Additionally, the study used Chile as a case study to conduct an in-depth analysis of the economic and environmental impacts of GGDP reform on the country, offering relevant policy recommendations and a 20-year implementation plan. The results demonstrate that adopting the GGDP accounting system not only effectively contributes to mitigating climate change but also provides a more accurate assessment of a country's economic health in terms of sustainability. Finally, the strengths and weaknesses of the model were discussed, and the sensitivity of its parameters was analyzed, providing valuable insights for further refinement of the GGDP accounting system in the future.

Keywords

Green GDP, Climate Change, AHP-CRITIC-CEI Model, E-K-means Clustering, Environmentally Friendly.

1. Introduction

In recent decades, the limitations of Gross Domestic Product (GDP) as a sole indicator of a country's economic health have become increasingly apparent, particularly in terms of its failure to account for environmental sustainability. GDP, which measures the total value of goods and services produced within a country, has long been considered the primary gauge of economic performance. However, GDP fails to reflect the negative externalities associated with economic growth, such as environmental degradation, resource depletion, and pollution. These shortcomings have prompted the introduction of alternative measures that better incorporate environmental and social factors into economic assessments[1].

One such alternative is Green GDP, a concept that integrates the costs of environmental degradation and natural resource depletion into the calculation of national economic performance. Unlike traditional GDP, GGDP seeks to provide a more accurate representation of a country's sustainable economic growth by accounting for the negative impacts of economic activities on the environment[2]. The concept of GGDP has gained traction in recent years, particularly as global concerns about climate change, environmental degradation, and resource scarcity have intensified. Countries that prioritize economic growth without regard to environmental consequences often face long-term ecological and economic challenges. Hence, a shift toward Green GDP could help promote a more balanced approach to development, one that recognizes the importance of environmental stewardship alongside economic growth[3].

This paper makes several significant contributions to the understanding and application of Green GDP as an alternative economic indicator that integrates environmental considerations into national accounting systems:

1) Development of a Comprehensive GGDP Framework: This study proposes a novel approach for calculating GGDP by incorporating environmental degradation and resource depletion into the national economic accounting system. The model combines methodologies such as the Analytical Hierarchy Process (AHP), CRITIC (CRiteria Importance Through Intercriteria Correlation) method, and the Comprehensive Environmental Index (CEI) to create a multi-dimensional framework for assessing GGDP. This framework provides a more accurate and comprehensive measure of economic performance by accounting for the ecological costs associated with economic activities.

2) Identification and Evaluation of Key Environmental Indicators: The paper identifies and evaluates critical environmental indicators-land use change, agricultural practices, fossil fuel consumption, and aerosol emissions-that significantly influence GGDP calculations. By selecting and assessing these indicators based on their relevance to climate change and environmental sustainability, the study provides a clear methodology for incorporating environmental factors into economic assessments, helping to bridge the gap in existing literature where environmental considerations in economic metrics are often underrepresented.

3) Validation of GGDP through Real-World Data: The study uses a dataset covering 44 countries over the period from 1991 to 2010 to validate the GGDP model. By applying the AHP-CRITIC method to calculate the weights and composite scores of environmental indicators, the paper demonstrates that GGDP reforms can significantly contribute to climate change mitigation. The empirical analysis reveals that countries adopting GGDP tend to fall into the "environmentally friendly" category, confirming the potential benefits of GGDP in reducing the environmental impacts of economic activities.

4) Introduction of the E-K-means Clustering Model: A key contribution of this study is the introduction of the E-K-means clustering model, which incorporates entropy theory to create a more refined clustering algorithm. This model is used to classify countries into environmentally friendly, moderate, and environmentally unfriendly categories based on their GGDP scores. The application of the E-K-means model enhances the accuracy of the clustering process, allowing for a deeper understanding of how countries are progressing in their adoption of GGDP and the corresponding environmental outcomes.

Through these contributions, this paper advances the understanding of GGDP as a tool for mitigating climate change and promoting sustainable economic development. It offers a comprehensive, data-driven evaluation of GGDP's practical application and provides a solid foundation for future research and policy initiatives aimed at integrating environmental factors into national economic accounts.

2. Methodology

The key mathematical notations used in this paper are listed in Table 1.

Table 1. Notations used in this paper.

Symbol	Description
C_e	Environmental degradation costs
C_r	Resource depletion cost
D_{fossil}	Amount of fossil energy consumed by an economy
P_{fossil}	The shadow price of fossil energy
P_{water_con}	Unit price of water resources
$ECSI$	Energy consumption structure index
$Index_{climate}$	Climate friendliness index
I_{land}	Land use change index
$I_{agriculture}$	Agricultural activity index
I_{fossil}	Fossil fuel dependence index
$I_{aerosol}$	Aerosol index
$i_{incineration}$	Incinerated crop residue index
i_{feaces}	livestock and poultry feces index
i_{N_2O}	NO_2 comprehensive emission index

(1) GGDP accounting model

The establishment of the green GDP accounting system in this article is based on SEEA (2012), which incorporates natural resources and the environment into the accounting system and establishes green GDP accounting indicators. The SEEA accounting system is a product of the combination of the current national economic accounting system and the economic concept of sustainable development[4]. It is the world's first unified accounting standard for environmental economic systems. On the basis of maintaining the core structure of GDP accounting, this accounting system establishes a statistical database of natural resources and environmental indicators to evaluate the relationship between GDP, natural resources and the environment, and calculates it by constructing environmental degradation accounting and resource depletion accounting Green GDP.

Based on the SEEA accounting system, the GGDP accounting equation can be expressed as:

$$GreenGDP = GDP - C_e - C_r \tag{1}$$

Where C_e is the cost of environmental degradation and C_r is the cost of resource depletion.

Figure 1 illustrates the work of our study.

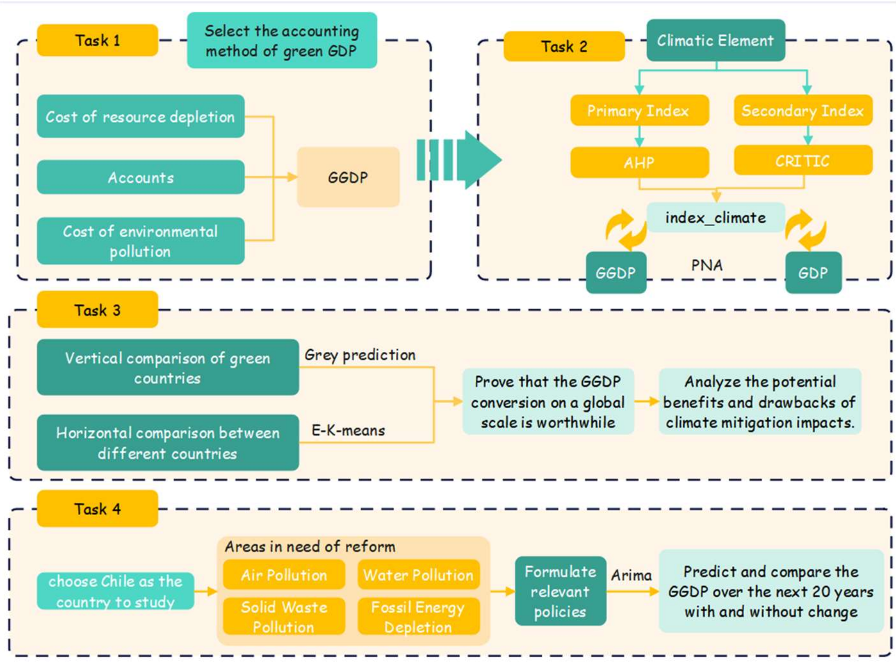

Figure 1. Our work.

1) Costs of environmental degradation

The cost of environmental degradation, also known as the cost of environmental pollution, refers to the value of the loss of environmental pollution and the cost of environmental protection, including mainly the cost of environmental degradation caused by air pollution, water pollution and soil pollution.

$$C_e = C_{air} + C_{water} + C_{soll} \tag{2}$$

Current studies have mainly used carbon emission costs to represent environmental costs, while ignoring SO2 emission costs and environmental damage caused by water and solid pollution[5]. Therefore, we choose the air pollution account represented by carbon and SO2 emissions, the water pollution account represented by wastewater emissions, and the solid pollution account represented by solid waste emissions and solid waste storage to measure environmental pollution costs.

2) Cost of resource depletion

Resource depletion cost is the value of resources consumed in economic activities. Considering the dependence of economic development on fossil energy and water resources, we choose fossil energy consumption and water resources consumption and measure the cost of resource depletion as follows.

$$C_r = C_{fossil} + C_{water\_con} \tag{3}$$

The cost of environmental improvement refers to the positive economic benefits of utilizing waste or improving environmental conditions, including the output value of comprehensive utilization of waste and the ecological benefits of gardening. However, some studies have shown that environmental improvement costs have less impact on GGDP accounting. Therefore, we adopt the accounting system shown in **Figure 2**.

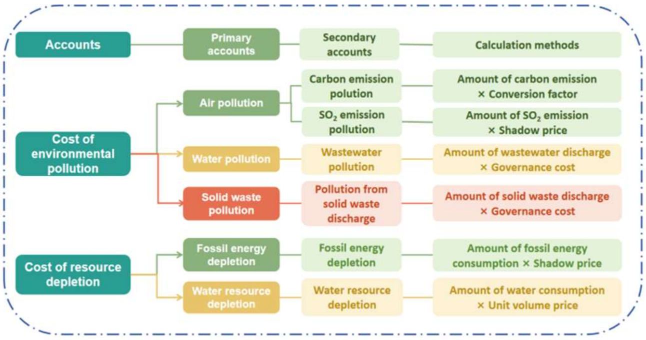

Figure 2. Accounting system.

GGDP is measured as follows. First, we measure various physical quantities of environmental pollution and resource depletion based on industrial data. Then, we convert them into real values expressed in monetary terms[6]. Finally, the costs of environmental degradation and resource depletion are removed from traditional GDP to obtain GGDP.

(2) AHP-CRITIC-CEI integrated modeling

1) Land use change

Globally, the distribution of carbon sources and sinks on the surface is largely determined by land-use change, and land-use and management changes produce long-term changes in carbon fluxes, which largely influence the amount of greenhouse gases in the atmosphere.

Here, we define land use change as the area of cleared cropland and pasture, abandoned farmland, timber harvesting, afforestation, and rotational farming. We then measure the changes in these areas over several years in different countries using Arcgis software to finally derive the average annual flux of carbon to the atmosphere due to land use change.

2) Fossil fuels

Due to the influence of various factors, the greenhouse gas emissions from the combustion of fossil fuels vary greatly among countries of different sizes, and the degree of a country's contribution to the mitigation of climate change cannot be well determined. Therefore, we plan to measure a country's dependence on fossil fuels through the Energy Consumption Structural Index (ECSI), with the following formula:

$$ECSI = \frac{E_{fossil}}{E_{total}} \times 100\% \quad (4)$$

Where ECSI denotes the Energy Configuration Index, E_{fossil} is fossil fuel consumption (including oil, gas and coal) and E_{total} is total energy consumption (including fossil fuels, renewable energy and nuclear energy, etc.)

3) Aerosols

The impact of aerosols on climate is a complex issue, as aerosols can affect the atmosphere and the climate system in many ways[7]. Here, we focus on their negative impacts on global climate change. Therefore, we selected the most abundant OC organic aerosols, as shown in **Figure 3**, and the SO42- inorganic aerosol particles, which are most closely associated with industrial pollution, as shown in **Figure 4**, to measure the impact of aerosol emissions on the climate in a region.

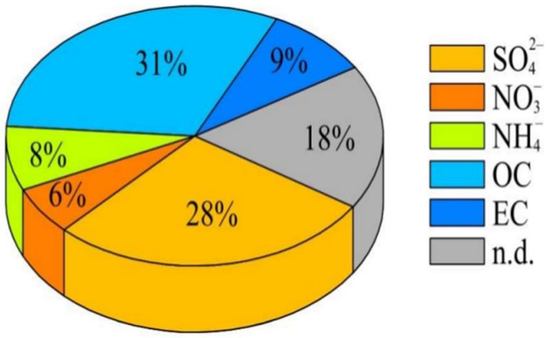

Figure 3. Levels of various aerosols in the atmosphere

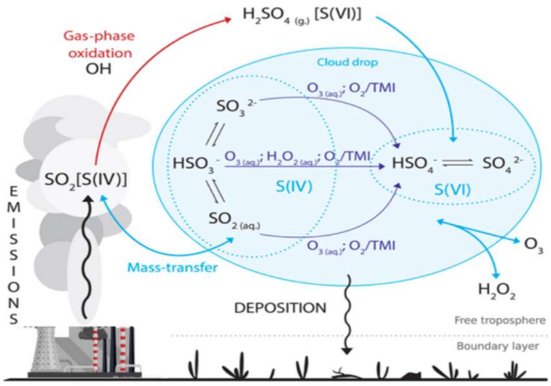

Figure 4. Chemistry of aerosols in industrial systems

In summary, the overall framework of indicators for measuring impact is shown in the **Figure 5**.

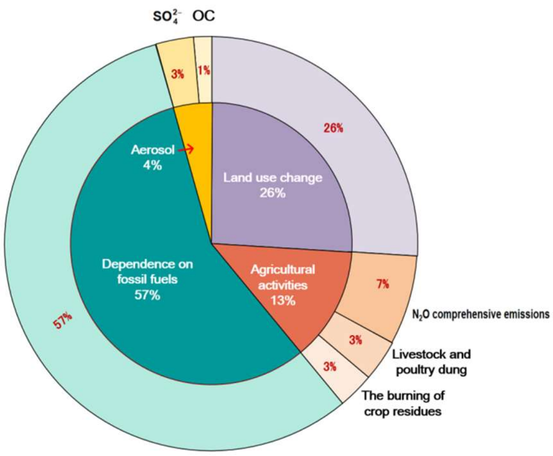

Figure 5. General framework of indicators for measuring impact.

(3) Dataset

Data collection is essential before a comprehensive system of indicators can be established. In order to measure the expected impact of adopting a green GDP accounting system on climate mitigation, we collected various indicators related to green GDP for 44 countries, as well as four primary and seven secondary indicators related to climate impact[8].

To ensure the applicability of the model in different regions, we collected time-series related data for these four regions to facilitate the development of optimal strategies. By checking official statistics and websites, we obtained rich data for different types of regions.

Table 2. Notations used in this paper.

Indicator	Data source
Carbon dioxide emissions	World Bank Open Data
Sulfur oxide emissions	World Bank Open Data
Wastewater production	EPS DATA
Solid waste emissions	Eurostat
Fossil energy consumption	CEIC
Water consumption	EPS DATA

(4) Calculation of the weights of secondary indicators based on the CRITIC method

CRITIC method is a method to objectively evaluate the weights of indicators through the differences and conflicts of indicators, which is an improvement of entropy right method, taking into account the differences between indicators while taking into account the correlation between indicators, and its specific calculation process is described below.

Indicator normalization. Considering that the indicators contain benefit-type and cost-type indicators, which have different trends in their effects on the final evaluation results, the vector normalization method is used to normalize the indicators without dimension:

$$x_{ij}^{*} = \begin{cases} x_{ij} \Big/ \sqrt{\sum_{i=1}^{n} x_{ij}^{2}} \\ \sqrt{\sum_{i=1}^{n} x_{ij}^{2}} \Big/ x_{ij} - 1 \end{cases} \tag{5}$$

Where: equation 5(a) is the formula for benefit-based indicators; equation 5(b) is the formula for cost-based indicators; x_{ij} is the initial value of each indicator; and x_{ij}^{*} is the normalized value of the indicator.

Then calculate the weights of the second-level indicators.

Hierarchical analysis is an empowerment method that involves subjective analysis of the elements by the decision maker, dividing the elements into hierarchical levels and creating a judgment matrix according to the importance of the elements in each level. The process is as follows:

In this paper, the judgment matrix is constructed using the commonly used 1~9 level comparison scale. Evaluation of indicator importance. According to the principle of scaling, the judgment matrix is built:

$$C = \begin{bmatrix} C_{11} & \cdots & C_{1n} \\ \vdots & \ddots & \vdots \\ C_{n1} & \cdots & C_{nn} \end{bmatrix}$$

Calculate the weights of the level 1 indicators. The weight coefficients of the indicators are calculated through the normalization process as:

$$W_i = \sqrt[n]{\prod_{j=1}^{n} C_{ij}} \Big/ \sum_{j=1}^{n} \sqrt[n]{\prod_{j=1}^{n} C_{ij}} \tag{6}$$

From the above calculations, we conclude that the weights of the four indicators at the first level, namely land use change, agricultural activities, dependence on fossil fuels and aerosols, are 26%, 13%, 57% and 4%, respectively. This leads to the formula for the calculation of the climate friendliness index, i.e., $Index_{climate}$:

$$Index_{climate} = 0.26 \times I_{land} + 0.13 \times I_{agriculture} + 0.57 \times I_{fossil} + 0.04 \times I_{aerosol} \tag{7}$$

3. Results

K-means algorithm is an unsupervised clustering algorithm, but K-means algorithm is always affected by the initialization of the necessary number of clusters in advance, in order to solve the accuracy of clustering and to determine the number of initial clusters, this paper proposes an entropy theory based K-means algorithm (E-K-means)[9].

The K-means algorithm is one of the most commonly used unsupervised learning algorithms for solving clustering problems. Let $X = \{x_1, \cdots, x_n\}$ be a dataset R^d in a d-dimensional Euclidean space, and let $B = \{b_1, \cdots, b_c\}$ be the center of c clusters. Let $g = [g_{ik}]_{n \times c}$, where g is a binary variable $(i.e.\ g_{ik} \in \{0,1\})$ denote the data point x_i belongs to the kth clustering cluster, $k = 0,1,\cdots,c$. The objective function of the K-means algorithm is:

$$J(g,B) = \sum_{i=1}^{n} \sum_{k=1}^{c} g_k \| x_i - b_k \| \tag{8}$$

The results of clustering based on the above E-K-means method are shown in **Figure 6**:

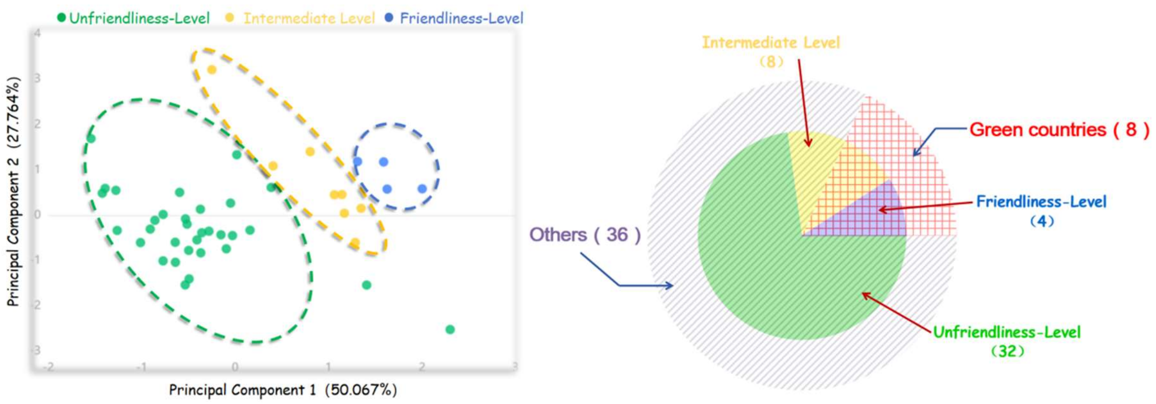

Figure 6. E-K-means method.

Analyzing this figure shows that the relationship coefficient β_i between green GDP and climate increases with the parameter λ in the AHP-CRITIC-CEI weather-economy prediction model. As far as the overall picture is concerned, the oscillation of the relationship coefficient β_i does not exceed 5.27% when the parameter λ is given to oscillate in the range of -10% to 10%, which indicates that the model is more stable[10].

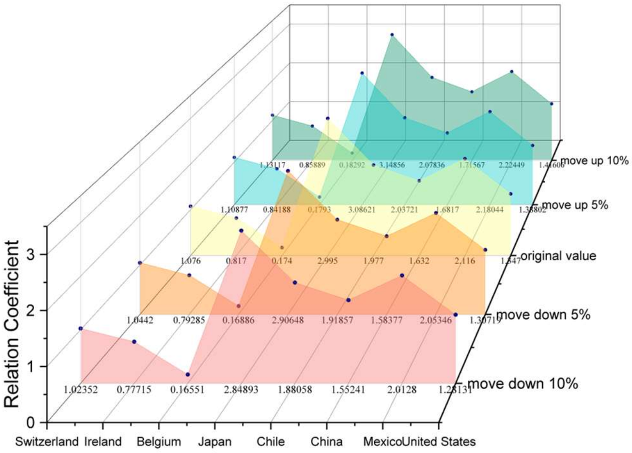

Figure 7. AHP-CRITIC-CEI meteorological and economic forecasting model

4. Conclusion and Future Work

This study demonstrates the potential of Green GDP (GGDP) as a more sustainable and comprehensive economic indicator compared to traditional GDP, particularly in addressing environmental concerns. By integrating environmental degradation and resource depletion into economic calculations, GGDP provides a clearer picture of a nation's true economic health, accounting for both economic output and environmental impact. Through the development of an AHP-CRITIC-CEI integrated model, we have successfully established a framework for evaluating the feasibility of GGDP and its implications for global climate change mitigation.

Our analysis, based on data from 44 countries, shows that GGDP reforms have a positive impact on climate change mitigation, as countries adopting GGDP reforms tend to fall into the "environmentally friendly" category. This confirms the validity of the GGDP approach in reducing environmental harm and fostering more sustainable economic development. Moreover, the case study of Chile highlighted the practical implications of GGDP adoption, including concrete policy recommendations and a roadmap for future implementation.

The strength of this study lies in its novel use of multiple indicators such as land use change, agricultural activities, fossil fuel dependence, and aerosol emissions, in combination with advanced methodologies like AHP, CRITIC, and E-K-means clustering. These methods provide a robust framework for assessing the environmental impact of economic activities, allowing for a more holistic understanding of how nations contribute to or mitigate climate change.

The future work could focus on several avenues as follows:

1) Expanding Indicator Sets: Although this study focused on four primary indicators, future work could consider additional indicators that may better capture the complexities of environmental sustainability, such as biodiversity loss, water usage, and waste management practices. This would help further refine the GGDP model and make it more universally applicable across different countries and regions.

2) Longitudinal Studies: Further studies should explore the long-term effects of GGDP adoption on national economies, especially in developing countries where balancing economic growth with environmental concerns is particularly challenging. This would provide a deeper understanding of the long-term benefits and potential trade-offs involved in transitioning to GGDP.

3) Refining the GGDP Calculation Model: While the AHP-CRITIC-CEI model has been validated, there is still room to enhance the accuracy of the GGDP calculation. Future research could explore alternative modeling techniques such as machine learning or system dynamics to

account for more complex interactions between economic activities and environmental impacts.

4) Global Comparison and Policy Implications: Future work could extend the analysis to a larger sample of countries and examine regional differences in GGDP adoption. This could provide valuable insights into how GGDP can be tailored to the specific needs and capacities of different countries and help policymakers design more effective strategies for sustainable economic development.

5) Incorporating Climate Change Models: Integrating more advanced climate change models and simulations into the GGDP framework could provide a more dynamic and accurate prediction of how GGDP reforms influence both national economies and global climate systems over time.

References

[1] Reay D S, Davidson E A, Smith K A, et al. Global agriculture and nitrous oxide emissions[J]. Nature climate change, 2012, 2(6): 410-416.

[2] Houghton R A. Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850–2000[J]. Tellus B: Chemical and Physical Meteorology, 2003, 55(2): 378-390.

[3] Schmidt T S, Steffen B, Egli F, et al. Adverse effects of rising interest rates on sustainable energy transitions[J]. Nature Sustainability, 2019, 2(9): 879-885.

[4] Chen B, Xiong R, Li H, et al. Pathways for sustainable energy transition[J]. Journal of Cleaner Production, 2019, 228: 1564-1571.

[5] Hazell P, Wood S. Drivers of change in global agriculture[J]. Philosophical Transactions of the Royal Society B: Biological Sciences, 2008, 363(1491): 495-515.

[6] Long H, Qu Y. Land use transitions and land management: A mutual feedback perspective[J]. Land use policy, 2018, 74: 111-120.

[7] Beillouin D, Cardinael R, Berre D, et al. A global overview of studies about land management, land-use change, and climate change effects on soil organic carbon[J]. Global change biology, 2022, 28(4): 1690-1702.

[8] Eichner M J. Nitrous oxide emissions from fertilized soils: summary of available data[R]. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, 1990.

[9] Skiba U, Smith K A. The control of nitrous oxide emissions from agricultural and natural soils[J]. Chemosphere-global change science, 2000, 2(3-4): 379-386.

[10] Hénault C, Grossel A, Mary B, et al. Nitrous oxide emission by agricultural soils: a review of spatial and temporal variability for mitigation[J]. Pedosphere, 2012, 22(4): 426-433