Green GDP Revolution Leading the Way to a Sustainable Future: The Case of China

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Abstract: Green GDP is a more comprehensive measure of the sustainability and environmental impact of economic development by taking ecological costs such as natural resource consumption and environmental pollution into account when counting gross domestic product (GDP). The Green GDP Index (GGDPI) is an indicator that measures the sustainability of economic growth and environmental protection, and is a derivative of Green GDP. It integrates data from both economic development and environmental protection to better measure the sustainability of economic development and environmental protection. By studying the relationship between the GGDPI and other climate indicators, the impact of the GGDPI on climate mitigation can be predicted, which in turn provides decision support for policy makers to help them better formulate measures to address climate change.

First, we collect data related to GGDPI, environment, etc. for GGDPI in China from 2010 to 2020, and pre-process the data. Then, using the superiority-disadvantage solution distance method, we set the indicators as positive and negative indicators, so as to analyze the country's use of GGDP as the main measure of the country's economic health.And then we build a linear regression model can help us analyze the relationship between GGDPI (Global Greenhouse Gas Reduction Index) and other climate indicators and infer from it the possible impact of GGDPI on climate mitigation.At last, based on the analysis of the above models, we propose how to achieve sustainable development in parallel with the country's economic development.

Keywords: Superior-disadvantageous solution distance method, Linear regression, Sustainable development

1 Introduction

Green GDP (Green GDP) refers to taking ecological costs such as natural resource consumption and environmental pollution into account when counting gross domestic product (GDP), so as to more comprehensively measure the sustainability and environmental impact of economic development. The introduction and development of Green GDP stems from the criticism of traditional GDP for ignoring environmental and ecological issues, and the advocacy of the concept of sustainable development.

Traditional GDP only considers economic activities such as monetary transactions, investment and consumption without considering the impact of these activities on the environment, thus reflecting the level of economic development to a certain extent, but not the level of sustainable development of society. For example, economic growth may be accompanied by environmental

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damage and ecological crises, the costs of which are often ignored, resulting in GDP growth that is at odds with people's living environment and health status[1].

In order to better measure the relationship between economic growth and sustainable development, the concept of green GDP was born. The basic idea is to include environmental and ecological issues as components of GDP, calculate the costs and losses of environmental and resource consumption, pollution control, etc., and deduct these costs from GDP to arrive at a more comprehensive and realistic economic growth figure. The introduction of green GDP reflects not only the growing prominence of environmental issues, but also the urgent need for sustainable development and ecological civilization[2-5].

The establishment of green GDP involves drawing knowledge from various disciplinary fields, such as environmental science, ecological economics, statistics, and more. In the specific context of mathematical modeling, it is crucial to consider how to accurately calculate the value of natural resources, assess the effects of environmental pollution, and formulate sensible policies for environmental protection. As green GDP continues to develop and improve, its application in economic decision-making, environmental protection policies, and the pursuit of sustainable development is becoming increasingly widespread. Consequently, green GDP has emerged as one of the important indicators and evaluation systems for global environmental governance and the promotion of sustainable development.

2 Model assumptions and notation

Based on our systematic and specific analysis of the problem, we assume that the question can be answered in detail using an appropriate mathematical model with a view to drawing reasonable conclusions.

(1) Assume that the data collected are real and reliable and will not have an impact on our model.

(2) Assuming that the factors affecting the green GDP issue have been fully considered by us.

Also, for the sake of description, we explain the symbols used throughout the text and their meanings in **Table 1**.

Table 1. Symbols and Meaning

Symbols	Description
w	Weight values from input layer to hidden layer
b_{ij}	Offset top of input layer to hidden layer
Z_{ij}	Weight values from the hidden layer to the output layer
d_x	Offset top of hidden layer to output layer
Y	GGDPI
X	GDP
β	Carbon dioxide emissions

3 GGDP Measurement Method

3.1 Mainstream Measurements of GGDP

There are many ways to calculate green gross domestic product (GGDP), such as GGDPI, CWCGDP and EDP, etc.,this paper chooses to use GGDPI as an alternative to GDP as the main measure of national economic health, because GGDPI is a comprehensive indicator that takes into account ecological costs and can more comprehensively assess the sustainability and environmental impact of economic development. In contrast, CWCGDP and EDP, while also concerned with sustainability and environmental issues, may not provide the same level of comprehensive and accurate information as the GGDP. At the same time, GGDPI can provide important guidance for policy formulation, through the analysis of GGDPI, it can assess the impact of economic development on the environment, and provide scientific basis for the formulation of environmental protection policies and sustainable development strategies, while CWCGDP and EDP may lack the same policy orientation and practical application in this regard. What's more, GGDPI calculations may be easier to achieve, as it is often extrapolated from existing economic and environmental data. In contrast, the calculation of CWCGDP and EDP may require more data collection and complex methods, which may present certain challenges in terms of data feasibility and implementation[6-9].

3.2 Model building

We collected data related to GGDPI, environment, and other data of GGDPI in China from 2010 to 2020, and firstly pre-processed the data. Next, we use the superiority and inferiority solution distance method to set the indicators as positive and negative indicators, so as to analyze the country's use of GGDP as the main measure of the country's economic health[10].

Step1:Using the superiority and inferiority solution distance method, the intermediate type indicators are forwarded, that is, they are uniformly transformed into very large indicators, and the intermediate type indicator series are $\{X_1, X_2\}$ The forwarding is performed, and the forwarding formula is **equation (1)**.

$$X_j^* = 1 - \frac{|X_j - X_{best}^*|}{max|X_j - X_{best}^*|} (j = 1,2,3) \tag{1}$$

where$\{X_1^*, X_2^*\}$ is the index series after forwarding.

Step2:Indicators with trending. The formula for converting a very small indicator into a very large indicator is **equation (2)**.

$$X_j^* = \frac{1}{X_j} (j = 7,8,9,10,11) \tag{2}$$

After the conversion so that the evaluation indicators maintain the same trend, to establish the same trending matrix.

Step:3 Normalize each indicator to eliminate the influence of the indicator magnitude to obtain the normalized matrix, and the normalization formula is **equation (3)**.

$$Z_{ij} = X_{ij} / \sqrt{\sum_{j=1}^{11} (X_{ij})^2} \; (i = 1,2,3) \tag{3}$$

Step4:According to the matrix of each indexZ_{ij} worth to the optimal vectorZ^+ and the worst value vectorZ^- which is the best object among the finite evaluation objectsZ^+ and the worst objectZ^- Step4: The best and worst objects among the finite evaluation objects are **equation (4)** and **equation (5).**

$$Z^+ = (Z_{i1}^+,\ Z_{i2}^+,\ \cdots,\ Z_{ij}^+)(i = 1,2,3; j = 1,2,3) \tag{4}$$

$$Z^- = (Z_{i1}^-,\ Z_{i2}^-,\ \cdots,\ Z_{ij}^-)(i = 1,2,3; j = 1,2,3) \tag{5}$$

Step5:Calculate the value of each index separatelyZ_{ij} value and the distance between the optimal solution and the worst solution of its corresponding indexD_i^+ withD_i^- : They are **equation (6)** and **equation (7).**

$$D^+ = \sqrt{\sum_{j=1}^{11}(Z^+ - Z_{ij})^2}\ (i = 1,2,\cdots,16; j = 1,2,\cdots,11) \tag{6}$$

$$D^- = \sqrt{\sum_{j=1}^{11}(Z^- - Z_{ij})^2}\ (i = 1,2,\cdots,16; j = 1,2,\cdots,11) \tag{7}$$

Finally, the distance between each index and its corresponding index optimal solution and the worst solution is combinedD_i^+ andD_i^- to establish a comprehensive evaluation model of green GDP.

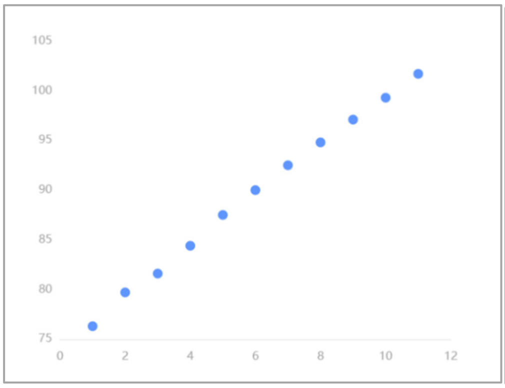
3.3 Model solving and result analysis

Table 2. Overall description of the results

Variable Name	Sample size	Maximum value	Minimum value	Average value	Standard deviation	Median	Variance	Kurtosis	Skewness	Coefficient of variation (CV)
GGDPI	11	101.7	76.3	89.536	8.383	90	70.267	-1.202	-0.12	0.0936213391703
GDP	11	632.86	68.55	284.474	235.419	101.598	55422.052	-1.948	0.411	0.8275574749696

Based on GGDPI(**Table 2**), the coefficient of variation (CV) is 0.094, which is less than 0.15. There is a small probability of outliers in the current data, and it is recommended to use the mean value for descriptive analysis.

Based on GDP(**Table 2**), the coefficient of variation (CV) is 0.828, which is greater than 0.15. There may be outliers in the current data, and it is recommended to analyze the indicators that are abnormal or have more prominent performance.



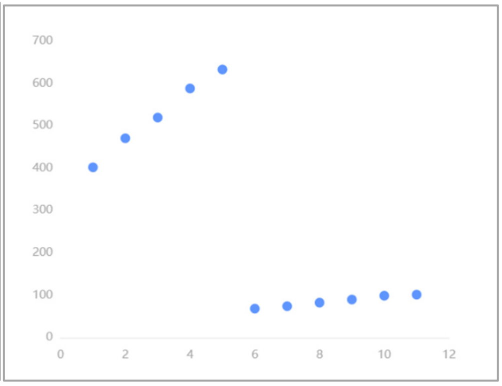
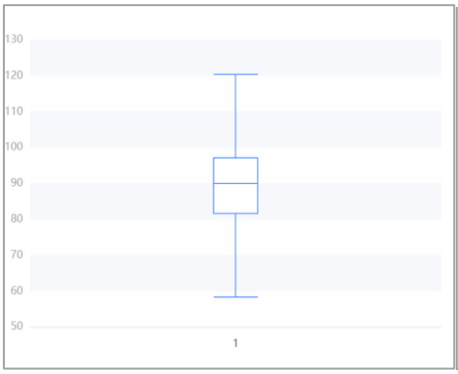


Fig. 1. GGDPI Scatter Plot **Fig. 2.** GDP Scatter Plot

The above figure shows the results of the centralized trend analysis of GGDPI(**Figure 1**) and GDP(**Figure 2**) frequency analysis in the form of a scatter plot, which can be used to estimate or predict the aggregate.



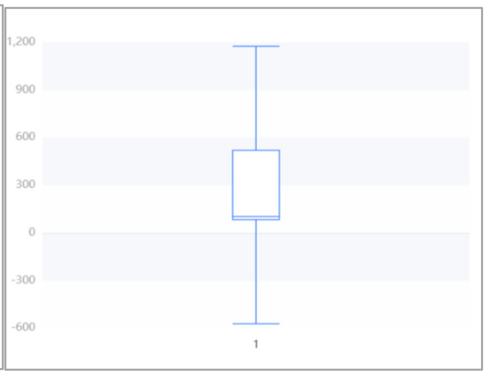


Fig. 3. GGDPI box diagram **Fig. 4.** GDP box diagram

The above figure shows the results of the discrete trend analysis of GGDPI(**Figure 3**) and GDP(**Figure 4**) frequency analysis in the form of a box line plot. The discrete trend measures the variance (stability) of the data distribution using statistical indicators such as the great value, the very small value, the 25% quantile, the median, and the 75% quantile.

Table 3. Calculation of indicator weights

item	Information entropy value e	Information utility value d	Weighting(%)
Energy intensity	0.922	0.078	3.481
GGDPI	0.905	0.095	4.228
Water Resource Utilization	0.945	0.055	2.433
Crude steel production	0.905	0.095	4.221

Forestry stockpile	0.883	0.117	5.173
Forest cover	0.27	0.73	32.395
GDP	0.738	0.262	11.633
GDP growth rate	0.948	0.052	2.304
Nitrogen oxide (NOx) emissions	0.843	0.157	6.978
CO2 emissions	0.816	0.184	8.167
Ammonia nitrogen emissions	0.834	0.166	7.381
Fertilizer use	0.861	0.139	6.186
Chemical oxygen demand COD emissions	0.878	0.122	5.421

The weight calculation results of entropy weighting method in **Table 3** show that the weight of Energy intensity is 3.481%, GGDPI is 4.228%, Water Resource Utilization is 2.433%, Crude steel production is 4.221%, Forestry stockpile is 5.173%, Forest cover is 32.395%, GDP is 11.633%, GDP growth rate is 2.304%, Nitrogen oxide (NOx) emissions is 6.978%, CO2 emissions is 8.167%, Ammonia nitrogen emissions is 7.381%, Fertilizer use is 6.186%, Chemical oxygen demand COD emissions is 5.421%, among which the index weight is The maximum value is Forest cover (32.395%) and the minimum value is GDP growth rate (2.304%).

Table 4. Calculation results of TOPSIS evaluation method

Index Value	Positive ideal solution distance (D+)	Negative ideal solution distance (D-)	Overall Score Index	Sort by
2010	0.62602651	0.27210343	0.30296666	3
2011	0.6224489	0.22986564	0.26969578	7
2012	0.61695865	0.22394973	0.26631883	8
2013	0.61069968	0.24197491	0.28378342	5
2014	0.60382614	0.24893589	0.29191718	4
2015	0.63524186	0.16408245	0.20527645	11
2016	0.64285962	0.17254002	0.21160179	10
2017	0.632465	0.20555868	0.24528982	9
2018	0.61628404	0.24060695	0.28079061	6
2019	0.43313715	0.35490588	0.45036358	2
2020	0.27537177	0.64660658	0.70132512	1

The composite degree score C value in **Table 4**, C = (D-) / (D+ + D-), is calculated with the formula that the numerator is the D- value and the denominator is the sum of D+ and D-; the greater the relative D- value, the farther the study object is from the worst solution, then the better the study object is; the greater the C value, the better the study object is.

Table 5. Display of intermediate values

item	Positive ideal solution	Negative ideal solution
Energy intensity	0.5020949	0.00047773
GGDPI	0.49529627	0.00000195
Water Resource Utilization	0.40283878	0.0025021
Crude steel production	0.564029	0.00012845
Forestry stockpile	0.52588807	0.00006186
Forest cover	0.93608307	0.00116864
GDP	0.54628568	1e-7
GDP growth rate	0.47854446	0.00000577
Nitrogen oxide (NOx) emissions	0.74512348	0.00001035
CO2 emissions	0.61648134	0.00003648
Ammonia nitrogen emissions	0.56733238	0.00009299
Fertilizer use	0.51402787	5e-8
Chemical oxygen demand COD emissions	0.57249524	0.00000458

Positive and negative ideal solutions (non-distance) in **Table 5** , these two values represent the maximum value of the evaluation index, or the minimum value (i.e., the optimal solution or the worst solution), respectively, these two values are used to calculate the D+ or D- value, the size of these two values does not have much significance.

Building a linear regression model can help us analyze the relationship between GGDPI (Global Greenhouse Gas Reduction Index) and other climate indicators and infer from it the possible impact of GGDPI on climate mitigation.We took GGDPI as the dependent variable and other climate indicators as the independent variables, and derived the linear relationship between GGDPI and other climate indicators by performing least squares regression analysis on the available data.

4 Conclusion

Table 6. Model results predictions

Variables	Coefficient
Constants	-9.484706108927867
Energy intensity	-154.08430418004173
Water Resource Utilization	27.028728570891417
Crude steel production	17.13474669509219
Forestry stockpile	15.408457651145227
Forest cover	-3.928430386209868

GDP	-0.002451283761060602
GDP growth rate	-0.5153961738195569
Nitrogen oxide (NOx) emissions	1.2965067377710966
CO2 emissions	-2.417803477129496
Ammonia nitrogen emissions	-0.8867950294578577
Fertilizer use	- 0.0015222483863820274
Chemical oxygen demand COD emissions	0.4505670715995933

According to **Table 6** , the equation of the model is as follows: GGDPI = -9.485 - 0.002*GDP - 0.515*GDP growth rate - 154.084*Energy intensity - 2.418*CO2 emissions + 17.135*Crude steel production + 0.451* Chemical oxygen demand COD emissions - 0.887*Ammonia nitrogen emissions + 1.297*Nitrogen oxide (NOx) emissions - 0.002*Fertilizer use + 27.029*Water Resource Utilization + 15.408*Forestry stockpile - 3.928*Forest cover .

5 Policy Recommendations

5.1 CO2 emissions policies

Reducing carbon dioxide emissions is essential for sustainable economic development. The government should prioritize policies and initiatives aimed at transitioning to cleaner and more sustainable energy sources, implementing carbon pricing mechanisms, and promoting green technologies to mitigate CO2 emissions.And it should focus on improving energy efficiency, promoting renewable energy sources, and implementing energy conservation measures to reduce energy intensity.Meanwhile， Promoting sustainable industrial practices and implementing effective pollution control measures are crucial.The government should enforce stricter environmental regulations, encourage industries to adopt cleaner production techniques, and invest in advanced pollution treatment technologies.

5.2 Natural resource development and conservation policies

The government should prioritize water conservation measures, invest in water infrastructure, and promote sustainable water use practices across various sectors to ensure long-term water security and environmental sustainability.Additionally, the government should strengthen measures to protect forests. This involves implementing stricter regulations against deforestation and illegal logging. Promoting afforestation and reforestation efforts is also crucial by encouraging the planting of new trees and restoring degraded forests. Furthermore, developing sustainable forest management practices is essential. This entails adopting strategies that preserve biodiversity, combat climate change, and enhance the overall resilience of ecosystems. By combining these actions, we can safeguard biodiversity, mitigate the impacts of climate change, and ensure ecological sustainability.

5.3 Develop green industrial policies

The government should increase investment in green technology research and development, formulate policies and regulations conducive to the development of green industries, provide financial support and tax incentives, cultivate green entrepreneurship and start-ups, strengthen talent training and skill upgrading, encourage international cooperation and knowledge exchange, advocate green supply chain management, improve public awareness and awareness of green industries, and monitor and evaluate the progress of green industry development.

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