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Greening the GDP——Exploration of the Relationship between Economy and Environment

Zhirun Yang, Long Chen

Tianjin University of Science and Technology, Tianjin, 300457, China

Abstract: *GDP has always been regarded as a significant indicator to measure the overall economic volume of a country. However, blindly pursuing high economic growth may cause waste of natural resources and damage to the ecological environment, which is not conducive to the long-term and sustainable economic development of the country. This paper aims to explore the deep relationship between economy and resources and environment through the study of Green GDP. Using CoalProducts, Fossil fuels (% equivalent primary energy), PM2.5 air pollution, mean annual exposure (micrograms per cubic meter) and other effective indicators, we developed a TOPSIS model based on The System of Environmental Economic Accounting (SEEA) to assess impacts on climate mitigation. It collects data from reliable sources, including around 42 countries and 18 statistical indicators. In addition, through the forecast of future resource consumption, population and GDP changes, it is further concluded that it is worthwhile to choose Green GDP as an indicator to measure the economy. This study takes China as an example, and the empirical results show that using Green GDP instead of GDP to calculate the national economy can effectively mitigate the negaitve impact of climate, which has certain reference value for the sustainable development and green economy construction of countries around the world.*

Keywords: *Green GDP; SEEA; TOPSIS; Climate Mitigation*

1. Introduction

1.1. Background

Gross Domestic Product, which is abbreviated to GDP, is the most important index about evaluating the strengh of a nation's economy. As the top priority for a country's economic strength and development prospects, GDP has long been the goal that world leaders follow. The higher the GDP, the stronger the momentum of economic growth. Yet degraded development is bound to consume resources and negative consequence will be resulted because of too much promotions for GDP growth. For instance, without considering about the conservation of tomorrow resources, a country with abundant mineral energy and oil resources will be able to exploit without restriction, aiming for its own trade and import. Such actions not only take up a lot of land, but also pollute the atmosphere, damaging biodiversity and water sources.

Thus, it can be seen that GDP is somewhat blind in terms of environmental protection, which may not be a reliable way to calculate a country's true economic health especially when it comes to sustainability. Based on the above reasons and those undesirale phenomena, since the 1970s, some international organizations have made beneficial explorations in national economic accounting and put forward the concept of Green GDP [1-3].

In the meanwhile, for proponents of green GDP, Geopolitics is gradually appearing in the public's vision, and increasingly international organizations are unable to organize large-scale global public welfare call activities. It is also a particular problem persuading countries to use Green GDP calculations instead of traditional GDP's as the primary reference for national development.

1.2. Literature Review

With the progression of science and technology, the first industrialized countries began to pay attention to the relationshi between economic growth and the pressure of resources and environment. In 1971, the Massachusetts Institute of Technology primarily proposed the *Ecological Demand Index (ERI)*. Subsequently, some international organizations such as the United Nations and the World Bank have done a lot of work in improving the research and promotion of GDP accounting. From 1973 to 1982, the United Nations began to study the methods and models of environmental statistics and prepared the

Outline for the Production of Environmental Statistics. Although no country has yet been able to complete a comprehensive economic accounting, efforts are continuously being made around the world. This led to the 1994 *Handbook of Integrated Environmental and Economic Accounting (SEEA) 1993* published. Since then, they have continued to revise and improve the manual, which is now the international guiding document for the conduct of integrated economic and environmental accounting, ending up with formula 1.

$$\text{Green GDP}=\text{GDP}-\text{COST}_{\text{Resources}}-\text{COST}_{\text{Environment}}+\text{SAVE}_{\text{Resources-Environment}} \tag{1}$$

In addition, countries are broadening and developing green GDP accounting methods according to their national conditions. From the international level, since the 1990s, the United Nations and other international organizations combining the United States, Canada, the Netherlands, the Philippines and other countries have carried out the exploration of green national economic accounting. The main comprehensive accounting systems include SEEA, ENRAP, SERIEE and NAMEA.

This paper adopts SEEA's balanced calculation method, which is GDP minus the cost of resource depletion amount and cost of environmental degradation, plus the benefit of resource and environment improvement to get green GDP. This Green GDP accounting method includes the calculation of the depleted value of environmental natural resources and the value of environmental loss. Therefore, aspects such as forest depletion, water resource depletion, and environmental pollution control value will be taken into account. The amount of carbon sequestration, discharge of pollutants, and consumption of water resources are related to the above indicators. After the Green GDP is selected, these indicators will be affected to varying degrees with the implementation of the policy. Therefore, it can be considered that the choice of this Green GDP accounting method can have an impact on the climate and environment, as shown in Figure 1.

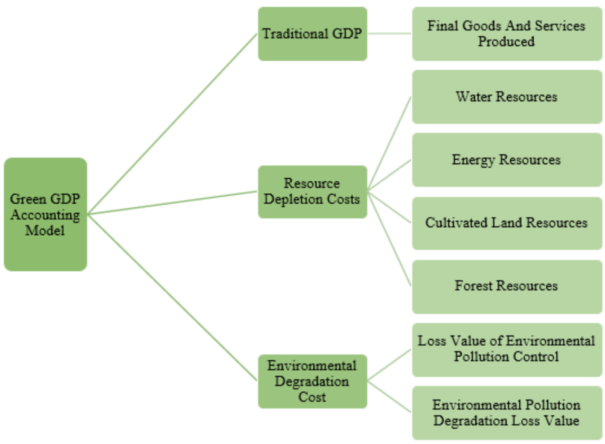

Figure 1: Green GDP Accounting Model

2. Main Text

2.1. Modeling

We developed an easily defendable model to measure the expected global impact on climate mitigation of countries adopting the Green GDP as the primary yardstick for national economic health. Our team believes that when the country takes Green GDP as the main standard, it is assumed that the country will introduce relevant policies to adjust its economic structure. In addition, according to the Green GDP standard selected by our team, we also assume that national policies will be more inclined to green and sustainable development, such as reducing the amount of trees felling, artificial forestation to increase forest expansion, reducing pollutant emissions through technological upgrading and other means, reducing the proportion of non-renewable resources in energy consumption, developing clean energy and other policies. It's hard to balance the impact of these policies with their actual implementation. But from a common-sense standpoint, we can be sure that this is going to have an impact on some of the national metrics. For example, PM2.5 air pollution, mean annual exposure (micrograms per cubic meter), Renewables (TWh growth-equivalent), Coal Products and so on have an impact. Therefore, our team selected a number of criteria to construct TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) comprehensive evaluation model for global impact on climate mitigation after Green GDP was selected as the main standard to measure national economic health in 42 countries across seven continents.

2.1.1. Model Preparation

(1) Assumptions

- All the costs involved in the model are related to national economic activities and belong to a part of national economic accounting.
- GDP, the cost of natural resource depletion and the cost of environmental degradation can all be measured reliably in terms of currency in circulation.
- The evaluation index will not change with the selection of Green GDP.
- The country will introduce relevant policies to adjust its economic structure.
- National policies will be more inclined to green and sustainable development, such as reducing the amount of trees cut down, artificial afforestation to increase forest expansion, technological upgrading and other measures to reduce pollutant emissions, reduce the proportion of non-renewable resources in energy consumption, development of clean energy and other policies.

(2) Data Collection & Processing

- We get our data from undata, ourworldindata, the World Bank Open Data, the World Energy Council, etc., so we can trust the veracity of the data. We carefully selected around 42 countries and 18 statistical indicators around the world. Among them, the countries span seven continents, including South America, North America, Europe, Africa, Asia and Oceania, and the statistical indicators include climate, water, forest and land.
- For many different countries and different times, it is difficult to obtain complete data at the time of data acquisition. However, in order to build the model, the missing value of data must be processed. In this regard, we use the homogeneous average interpolation method to confirm the type of missing value, and replace the missing value with the average value of the class. Given that many of the data are close to random omissions, maximum likelihood estimates can be used to supplement the data when predicting and assessing the global impacts of climate mitigation. And its performance is optimal when the observed data is large enough, especially its high approximation rate.
- Indicators used to evaluate the impact of Green GDP on the environment include Coal Products, Fossil fuels (% equivalent primary energy), PM2.5 air pollution, mean annual exposure (micrograms per cubic meter) and so on, which are smaller to have a better impact on climate mitigation. Meanwhile, for the problem that different data have different dimensions, we can't put them together directly for calculation. Therefore, it is necessary to carry on the data forward processing and standardization processing.

$$posit_x = max(x) - x \tag{2}$$

- Combine the data and find the maximum and minimum values for each indicator. On the basis of the processed data, the formula for calculating the score is constructed. Since there are negative numbers in the evaluation criteria, it is necessary to normalize the data again, and then carry out positive processing on this basis. Since there are different symbols among different countries in the evaluation criteria such as forest expansion, it is necessary to standardize these data with different symbols again.

$$\tilde{Z}_{ij} = \frac{x_{ij} - min\{x_{1j}, x_{2j}, \cdots, x_{nj}\}}{max\{x_{1j}, x_{2j}, \cdots, x_{nj}\} - min\{x_{1j}, x_{2j}, \cdots, x_{nj}\}} \tag{3}$$

- Finally, aiming to eliminate dimensional effects, the data is standardized using the following formula.

$$z_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{n} x_{ij}^2} \tag{4}$$

(3) Concepts and more detailed formulas Involved

- The cost of depletion of natural resources includes one-time consumption of natural resources and multiple consumption of natural resources. For example, non-renewable mineral resources, part of renewable forest resources (timber forest) and water resources, which have the nature of intermediate consumption, belong to one-time consumption of natural resources; Land resources, part of the renewable forest resources (special forests, shelter forests, etc.), the application of these resources is similar to the nature of the application of fixed assets, so they belong to the natural resources with multiple consumptions.

- Water resource depletion value(W):

$$W = water\ resource\ price \times water\ resource\ depletion \tag{5}$$

- Energy resource consumption reduction value(EV):

$$EV = energy\ resource\ consumption\ reduction \times energy\ resource\ price \tag{6}$$

- Arable land consumption value(A):

$$A = change\ area\ of\ arable\ land\ resources \times \frac{priceof\ arable\ land\ resources}{area} \tag{7}$$

- Price of cultivated land per unit area(C):

$$C = \frac{gross\ agricultural\ product\ of\ the\ region}{cultivated\ land\ area\ of\ the\ region\ in\ the\ year} \tag{8}$$

- Value of depletion of fishery resources(FR):

$$FR = Gross\ Marine\ catch\ value + Total\ value\ of\ freshwater\ fishing \tag{9}$$

- Environmental degradation cost is divided into environmental protection expenditure and environmental degradation cost. Environmental protection expenditure refers to the value actually paid for environmental protection, while environmental degradation cost refers to the loss of environmental pollution and the value that should be paid for environmental protection.

- Loss value of forest resources(L):

$$L = loss\ of\ total\ stock\ of\ live\ wood\ resources \times \frac{price\ of\ live\ wood\ resources}{area} + change\ area\ of\ forest\ resources \times \frac{price\ of\ forest\ resources}{area} \tag{10}$$

- The actual treatment cost is the total amount of capital invested in the treatment of environmental pollution in each region. The virtual treatment cost is estimated by using the maintenance cost pricing method, and the calculation formula is as follows:

$C_{virtual}$ is the virtual treatment cost, Q is the emission of pollutants, X is the unit treatment cost of pollutants, i is the ith pollutant, and n is the total number of n pollutants.

$$C_{virutal} = \sum_{i=1}^{n} Q_i \times X_i \tag{11}$$

- Natural disaster loss value accounting: This paper mainly calculates the loss value of forest fire, geological disaster, earthquake disaster, drought loss and Marine disaster loss value.

$$C_{self} = C_{forest} + C_{geology} + C_{earthquake} + C_{drought} + C_{ocean} \tag{12}$$

2.1.2. Model Establishment

- **Step 1:** Calculation of weight

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In this model, Entropy Weight Method is used to calculate the weight. Entropy Weight Method is a method introduced by American mathematician Shannon. According to the definition of information entropy, the degree of dispersion of an index can be judged according to the entropy value. The greater the information entropy value of the index, the smaller the degree of dispersion of the index, and the greater the influence of the index on the comprehensive evaluation[4-6].

Accordingly, we have n countries and m evaluation indexes, and non-negative matrix can be obtained through the above data processing:

$$\tilde{Z} = \begin{bmatrix} \tilde{z}_{11} & \tilde{z}_{12} & \cdots & \tilde{z}_{1m} \\ \tilde{z}_{21} & \tilde{z}_{22} & \cdots & \tilde{z}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2} & \cdots & \tilde{z}_{nm} \end{bmatrix} \tag{13}$$

Calculate the proportion of the i-th sample in the i-th index, and regard it as the probability used in the calculation of relative entropy. Then calculate the probability matrix p, each entry p_{ij}:

$$p_{ij} = \frac{\tilde{z}_{ij}}{\sum_{i=1}^{n} \tilde{z}_{ij}} \tag{14}$$

The information entropy of each index is calculated, and the information utility value is calculated, and the entropy weight of each index is normalized.

Information entropy of the j-th index:

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} p_{ij}\ln(p_{ij}) \ (j = 1,2,\cdots,m) \tag{15}$$

The greater the utility value of information, the more information it corresponds to. Definition of information utility value:

$$d_j = 1 - e_j \tag{16}$$

The entropy weight of each index can be obtained by normalizing the information utility value:

$$W_j = d_j / \sum_{j=1}^{m} d_j (j = 1,2,\cdots,m) \tag{17}$$

The weight determined by entropy weight method is shown in Table 1:

Table 1: The Result of Weight Calculation

Indicators	***Weight***
Emissions of Carbon Dioxide per Capita (ton)	0.0297
Annual CO2 emissions from oil	0.0122
Coal Products	0.0098
Natural Gas	0.0123
Electricity	0.0128
Oil Products	0.0137
Fossil fuels (TWh)	0.0139
Fossil fuels (% equivalent primary energy)	0.1696
Mismanaged plastic waste to ocean per capita (kg per year)	0.0131
PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)	0.0266
Forest area (% of land area)	0.0612
Methane emissions (metric tons of CO2 equivalent per capita)	0.0215
Nitrous oxide emissions (metric tons of CO2 equivalent per capita)	0.0159
Tree Cover Loss (hectares)	0.0158
Forest Area (% of Land Area)	0.0727
Total including LUCF (per capita)	0.0840
Renewables (TWh growth - equivalent)	0.1338
Adjusted savings: natural resources depletion (% of GNI)	0.2817
Total	1.0000

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After a country changes its GDP to Green GDP, it can be believed that the country will develop in a green and sustainable direction, which will affect these indicators. Therefore, our team believes that the evaluation system established by these indicators can be used to measure the impact of a country's adoption of Green GDP on climate mitigation.

- **Step 2:** TOPSIS MODEL

The TOPSIS Model was proposed by C.L. wang and K. Yoony. A commonly used comprehensive evaluation method, which can make full use of the information of the original data and accurately reflect the differences among the evaluation schemes.

$$Define\ the\ maximum: Z^+ = (Z_1^+, Z_2^+, \cdots, Z_m^+) = (max z_{11}, z_{21}, \cdots, z_{n1}, max z_{12}, z_{22}, \cdots, z_{n2}, \cdots, max z_{1m}, z_{2m}, \cdots, z_{nm}) \tag{18}$$

$$Define\ the\ minimum: Z^- = (Z_1^-, Z_2^-, \cdots, Z_m^-) = (min z_{11}, z_{21}, \cdots, z_{n1}, min z_{12}, z_{22}, \cdots, z_{n2}, \cdots, min z_{1m}, z_{2m}, \cdots, z_{nm}) \tag{19}$$

Here, we choose Euclidean distance to define the maximum and minimum values of the ith evaluation index and this index respectively as follows:

$$D_i^+ = \sqrt{\sum_{j=1}^{m} \widehat{W_j}\left(z_j^+ - z_{ij}\right)^2} \tag{20}$$

$$D_i^- = \sqrt{\sum_{i=1}^{m} \widehat{W_j}\left(z_j^- - z_{ij}\right)^2} \tag{21}$$

Therefore, the non-normalized score of the i-th index is calculated:

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{22}$$

Normalized the index:

$$\widetilde{S_i} = S_i / \sum_{i=1}^{n} S_i \tag{23}$$

2.2. Results

Table 2: The Ranking of the Countries We Chose about the Effect of Climate Mitigation in table

Countries	***Effect Degree***	***Ranking***
China	0.0413	1
Russia	0.0376	2
Kazakhstan	0.0341	3
…	…	…
Poland	0.0161	40
Singapore	0.0157	41
Bangladesh	0.0150	42

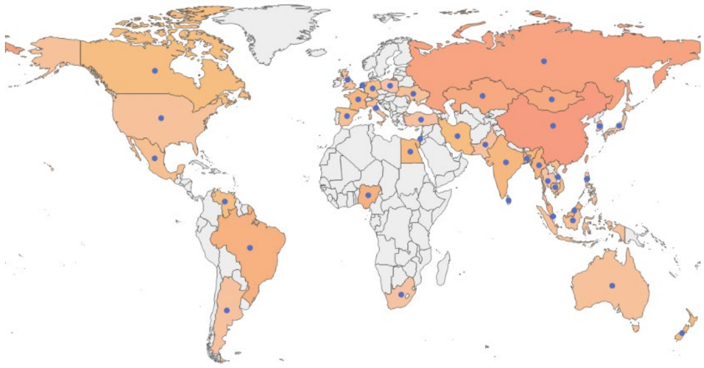

Figure 2: The Ranking of the Countries We Chose about the Effect of Climate Mitigation in figure

As shown in Table 2, the influence is different for each country and we show it in different shades of orange, the darker the color, the more influence that country has. It can be seen from the figure 2 that China, Russia, Kazakhstan and Mongolia rank higher. Here's what we got:

2.3. Analysis of the Result

In the illustration above, we can conclusion that most of the countries at the top of the rankings are very large economies and rich in natural resources, showing a strong correlation with domestic productivity and resource consumption in terms of expected global impacts on climate mitigation. Take Britain as an example, The UK comes 28th out of the 42 countries analysed, and in fact scores are very close all the way down to the 20th. We think this is due to the fact that these countries have less of a balanced share of new energy use than the countries at the top of the rankings, or that the UK has been implementing sustainable development policies for some time. Over the past 30 years, the government has significantly reduced the state assets and slowed down the development of social welfare programs. Currently, the UK has initially developed a market-based, government-led, the interactive system with all enterprises, the public sector and residents as the main body has taken a leading position in the world in many aspects, such as low-carbon technology research and development, policy development and construction, and national awareness. To some extent, the UK has broken through the initial bottleneck of developing a low-carbon economy and embarked on a new path of sustainable development, which lays a solid foundation for the UK to implement its low-carbon plan[7-8].

3. Model Application Based on China

Considering that China's data is relatively easy to obtain and its statistics are relatively complete, we choose China as the research object to conduct a more in-depth analysis of the possible impact of this change. In this part, we directly use the model and indicators on the basis of formulas (1), compare the specific changes in China's use or conservation of natural resources before and after using GDP and Green GDP for accounting. Formulas (5) to (12) are used to measure Resource Depletion Costs and Environmental Degradation Costs. Among them, we focus on non-renewable resources such as timber, oil and gas, and the impact on population due to the use of Green GDP. Data are obtained from China Statistical Yearbook, China Price Statistical Yearbook, China Land and Resources Statistical Yearbook, as well as relevant statistical yearbooks and statistical bulletins of various provinces.

3.1. The prediction of Green GDP

Through the method above, China's green GDP from 2007 to 2016 can be calculated. In the calculation of water resource depletion value, Fi (the total value created by regional water producers) is difficult to obtain, so we assume that the value of Fi is the same as the gross aquatic product of region i.

For forest depletion resources, due to the lack of forest resource depletion over the past years in statistical data, the five-yearly woodland area and the total stock of standing trees can be used as the basic index of forest resource depletion. Meanwhile, due to the constraints of subsequent relevant data of other indicators, Green GDP can only be calculated until 2016. Therefore, based on the calculable Green GDP of 2016 and previous years, the team made predictions for the later years. In addition, due to the emergence of COVID-19 in 2019, many cities have been irregularly suspended production and resumed production in accordance with China's policies, making it difficult to measure the correlation between

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changes in data indicators and green GDP development. Therefore, our team chooses to forecast the 2017-2019 Green GDP data and can compare the predicted resource usage with the actual predicted amount and further analyze the results (this is because China is still determined by measuring the national economic health standard based on GDP).

3.2. Environmental pollution degradation loss value calculation

Due to environmental pollution, it is difficult to obtain the accelerated depreciation rate of fixed assets. Therefore, this method considers that 5.5% of the total industrial output cost is used for the total maintenance expenditure of fixed assets and equipment, and the proportion of the accelerated depreciation cost of fixed assets caused by environmental pollution degradation is 5.2% of the total maintenance expenditure. We can do that by looking at gross industrial output.

$$C_{fixed} = W_{industrial} \times 5.5\% \times 5.2\% \tag{24}$$

3.3. The final Green GDP calculation

Table 3: The Result we Achieved

year	Trillion yuan
2007	221187.00
2008	261678.20
2009	295456.20
2010	363239.60
2011	395046.80
2012	470582.70
2013	518624.60
2014	570845.20
2015	625725.60
2016	690712.40

We use the shade of the color of the picture to represent the per capita Green GDP data. The darker the orange, the higher the Green GDP value, as shown in Table 3.

Figure 3: Green GDP per Capital in China

As we can see from the figure 3, in some regions with better economic development, the cost of resource and environmental pollution is small. However, some regions with lower economic development level are more dependent on resources and environment. Combined with GDP analysis, it can be found. The main characteristics of some provinces are low level of economic development and great impact on resources and environment. The main characteristics of provinces are low level of economic development and great impact on resources and environment. The main feature of some provinces is that the level of economic development is relatively flat, but they are somewhat dependent on resources and the environment. Such as Shandong, Hebei. For these provinces, macro-control should be carried out from the policy, and efforts should be made to transform from the extensive economic growth mode to the intensive economic growth mode[9-10].

3.4. Specific changes in natural resources

For the consumption of coal resources, we assume that the selection of Green GDP as the main standard to measure the health of the national economy will bring some resistance to the growth of consumption of these non-renewable resources. Therefore, Gardner and McKenzie (1985) introduced a damping effect based on Hult's model to mitigate the damped trend of higher linear trends for prediction, as shown in Figure 4 and Table 4.

Projections for coal consumption:

Table 4: Mdel Fit 3

Fit Statistic	*Mean*	*Minimum*	*Maximum*	*Percentile*						
				5	*10*	*25*	*50*	*75*	*90*	*95*
Stationary R-squared	0.203	0.203	0.203	0.203	0.203	0.203	0.203	0.203	0.203	0.203
R-squared	0.747	0.747	0.747	0.747	0.747	0.747	0.747	0.747	0.747	0.747
RMSE	31500.096	31500.096	31500.096	31500.096	31500.096	31500.096	31500.096	31500.096	31500.096	31500.096
MAPE	5.778	5.778	5.778	5.778	5.778	5.778	5.778	5.778	5.778	5.778
MaxAPE	12.063	12.063	12.063	12.063	12.063	12.063	12.063	12.063	12.063	12.063
MAE	21665.175	21665.175	21665.175	21665.175	21665.175	21665.175	21665.175	21665.175	21665.175	21665.175
MaxAE	46388.088	46388.088	46388.088	46388.088	46388.088	46388.088	46388.088	46388.088	46388.088	46388.088
Normalized BIC	21.406	21.406	21.406	21.406	21.406	21.406	21.406	21.406	21.406	21.406

ACF and PACF graphics show residuals as white noise:

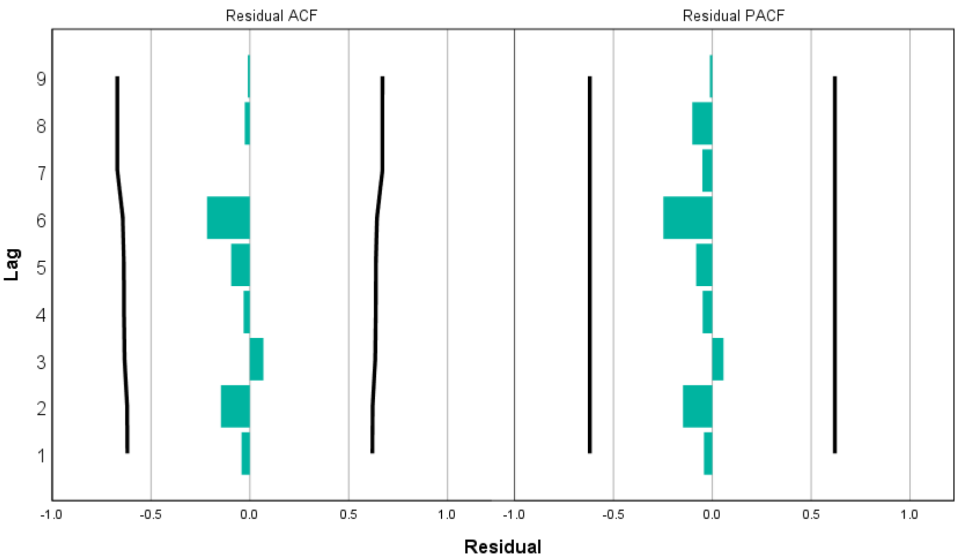

Figure 4: Residual of Coil Consumption

3.5. Results & Analysis

For the prediction of coal consumption, it can be seen that the numerical growth of coal consumption is affected by some kind of resistance. Overall, it can be found that the decay time prediction is finally close to the true value. This may be caused by China's sustainable development policy. Among them, our team specifically conducted research on China's coal decline in 2014. The main reason for the decline in coal consumption is due to the slowdown in economic growth, the continuous elimination of backward industries, and the continuous increase in production capacity. At the same time, the continuous adjustment of the energy structure and the increase in the proportion of renewable energy use are also important reasons for restraining the growth of coal demand. After adopting Green GDP, we decide that China could better grasp the relationship between natural resource use and people's demand. While

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achieving economic development, protect the ecological environment, as shown in Figure 5.

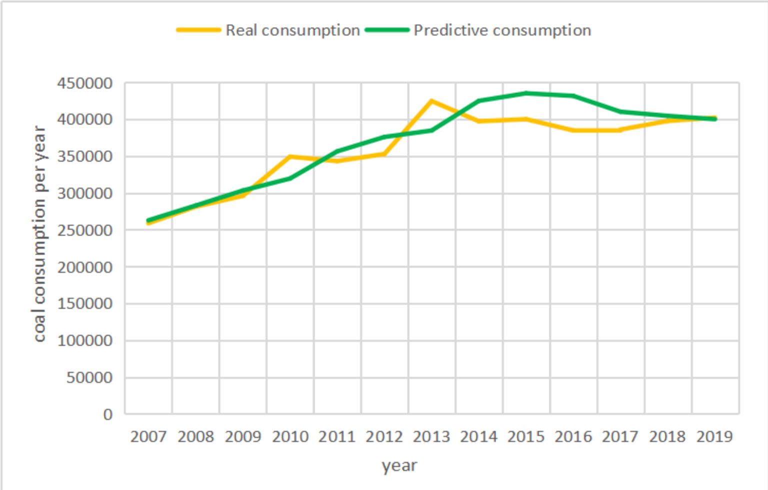

Figure 5: The Real and Predictive Consumption of Coal

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