Problem Chosen	2023 MCM/ICM Summary Sheet	Team Control Number
F		2300870

Together for a Green World

Summary

The economy is the top priority in the development of every country, and the ecological environment is the foundation and guarantee of a country and a nation. With the environment exacerbated rapidly, countries are realizing the importance of environmental protection in the process of economic development. In this situation, the **Green Gross Domestic Product (GGDP)** meets the upcoming challenges to define the environmental factors in the economic measuring system.

Previous research has primarily relied on building a scientific index of sustainable economic welfare and emphasizing the advantages of GGDP in achieving long-term sustainable economic development, realizing industrial structure upgrading, and enhancing the sense of fairness and happiness of all social citizens. Whether the GGDP has a significant impact on environmental improvement needs more studies.

Therefore, this paper first uses the **literature survey method** to determine a more general and applicable formula for calculating green GDP, followed by a **time series model** prediction based on historical data on GDP and GGDP. In the process of building the regression model, the paper selects the indicators that have a significant impact on the ecological environment of major countries around the world by **the entropy method** and **Coefficient of variation model** construct the climate index as the dependent variable, and then constructs two **regression models** with GDP and green GDP as the independent variables and makes predictions to investigate whether the use of green GDP indicators contributes to environmental improvement compared to GDP.

The findings show that in the short term, the differences in the effects of GDP and GGDP on environmental quality are not significant, but **in the long term**, the GGDP-accounted development level can improve environmental quality.

Then, taking China, the biggest developing country in the world, as an example, the paper investigated the potential benefits and drawbacks of using GGDP. In order to lower the loss of GDP in the pursuit of green growth, suggestions that developing countries should try to research and develop low-carbon technologies and actively promote the establishment of capital and technological sharing mechanisms around the world are proposed.

Keywords: GGDP; impact on environment; regression model; developing countries

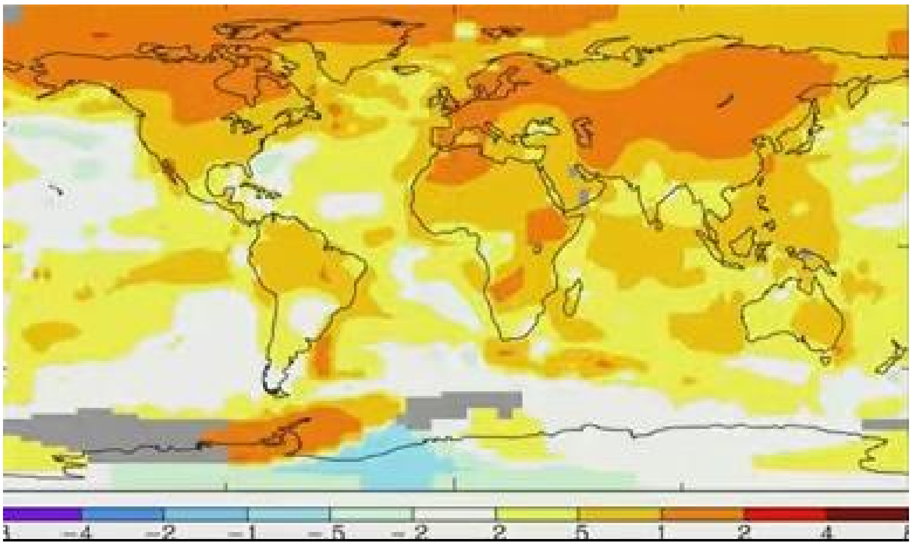
Contents

1 Introduction

1.1 Problem Background

Gross domestic product (GDP) is a monetary measure of the market value of all the final goods and services produced and sold (not resold) in a country in a given period of time. GDP is a common standard to measure the development degree of a country or region, especially the comprehensive economic strength. However, with the competition between countries intensifying, more and more countries are pursuing GDP growth without any consideration about conserving resources for future. In order to integrate green concept into development evaluation, some countries introduce the concept of Green GDP to evaluate and compare their economies.

Green GDP is a measure of economic growth that takes into account the environmental costs of development. It is an alternative to traditional Gross Domestic Product (GDP) that does not consider environmental costs. It is an effective way to measure the sustainability of economic growth and development and takes into consideration the environmental costs of production, such as pollution, resource depletion, and climate change. It also takes into account the benefits of environmental protection, such as improved air, water quality, and increased biodiversity. In a word, it is an important tool for governments to assess the sustainability of their economic growth and development.



（Figure credit: Japan Times）

Figure 1 Global warming rate

1.2 Restatement of the Problem

Considering the background information and restricted conditions identified in the problem statement, we need to solve the following problems:

- **Problem 1** Give Green GDP a definition and select an appropriate model from the available literature to replace GDP as the primary measure of economic health. There are many models of green GDP, and the model we choose must be representative enough and have a large impact on climate mitigation.
- **Problem 2** Describe the possibility of replacing traditional GDP with GGDP, and analyze the impact of such changes on solving national or even global problems such as resource depletion and environmental pollution.
- **Problem 3** Determine whether the model shows that such the shift is worthwhile on a global scale by comparing the potential benefits of mitigating climate impacts with the potential disadvantages of the effort needed to replace the status quo.
- **Problem 4** Choose a country, analyze the impact of the change in depth, and conclude whether the change is good for the future development of the country.
- **Problem 5** Based on our country-specific analysis, write a report to the country's leaders on whether that country should change its accounting methods.

1.3 Literature Review

GDP (Gross Domestic Product), used to measure national income, is a core economic indicator for developed economies. In recent years, however, some people are opposed to GDP because of the fact that GDP does not take into account environmental externalities and the depletion of natural resources. For decades, new environmental economists have been working to develop methods to adjust traditional GDP and its national conservation measures for various environmental impacts. Despite these efforts, traditional GDP still dominates and is the central statistical tool used by governments and international organizations to assess economic conditions and plan economic policies.

There are two typical countries when it comes to green GDP - the United States and Japan.

The first country in the world to start research on green GDP was the United States, where the cost of environmental pollution control was already accounted for during the Ford administration and supported by numerous commissions during the Carter and Bush administrations. In 1989, the American economists Daly and Cobb proposed the use of Index of Sustainable Economic Welfare to account for GDP. In 1992, BEA (the Bureau of Economic Analysis) developed integrated environmental and economic satellite accounts, and in 1994, for the first time, they conducted an accounting of environmental quality impacts and depletion of underground mineral resources. In 2019, a forum was held in New York to discuss the feasibility of green GDP accounting, and today the U.S. has developed an environmental-economic accounting system that fits local conditions.

Japan is one of the world's largest economies. In the 1990s, Japan did not follow the United Nations method for systematic accounting, but it paid much attention to environmental values and set up a special organization to work on green GDP accounting. Japan carried out two environmental economic accounts in 1998 and 2000, carrying out a hybrid integrated accounting system of economic activities and environmental compound valuation, including the National Economic Accounting (NEA) and the Environmental

Accounting (EA), and summarizes "environmental efficiency improvement indicators" by compiling and analyzing the relationship between these two types of data. In the Environmental Economic Accounting Report released in 2009, Japan included a hybrid integrated accounting in its environmental policy. Japan also presented a SEEA-CF overview document and two reports on March 31, 2016.

At present, nearly a quarter of countries have explored green GDP accounting, including Japan, the United States, the Netherlands, Finland, Indonesia, Malaysia, the United Kingdom, Germany, Canada, India, Norway, Austria, France, Sweden, Chile and other countries and regions, which are involved in the research and practice of environmental economic accounting to different degrees. However, no consistent, complete and operational accounting system has been formed yet. The international community is currently in the period of experimentation and exploration for the construction of physical and value accounts, liability concepts, resource categories, resource assets, accounting methods, and other aspects of these accounts.

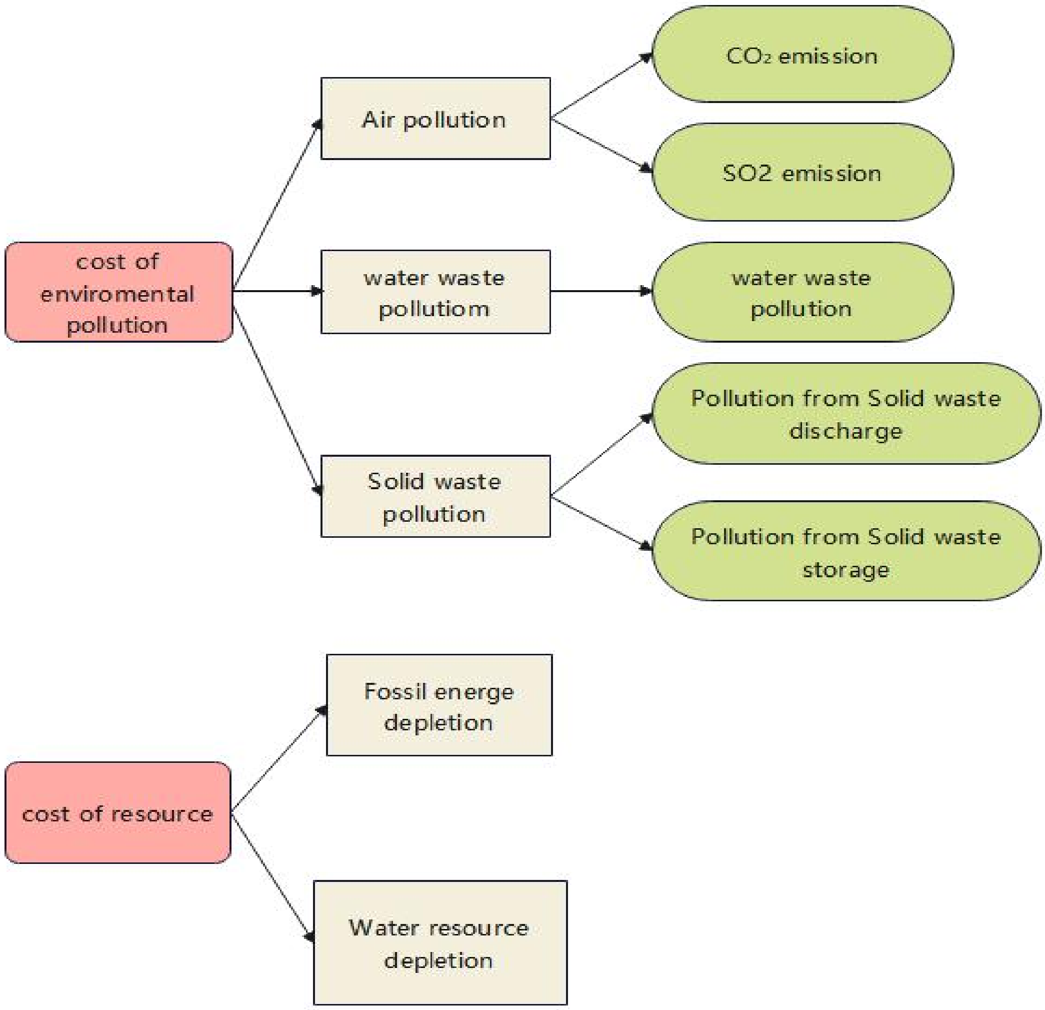


Figure 2 Accounting system

1.4 Our Work

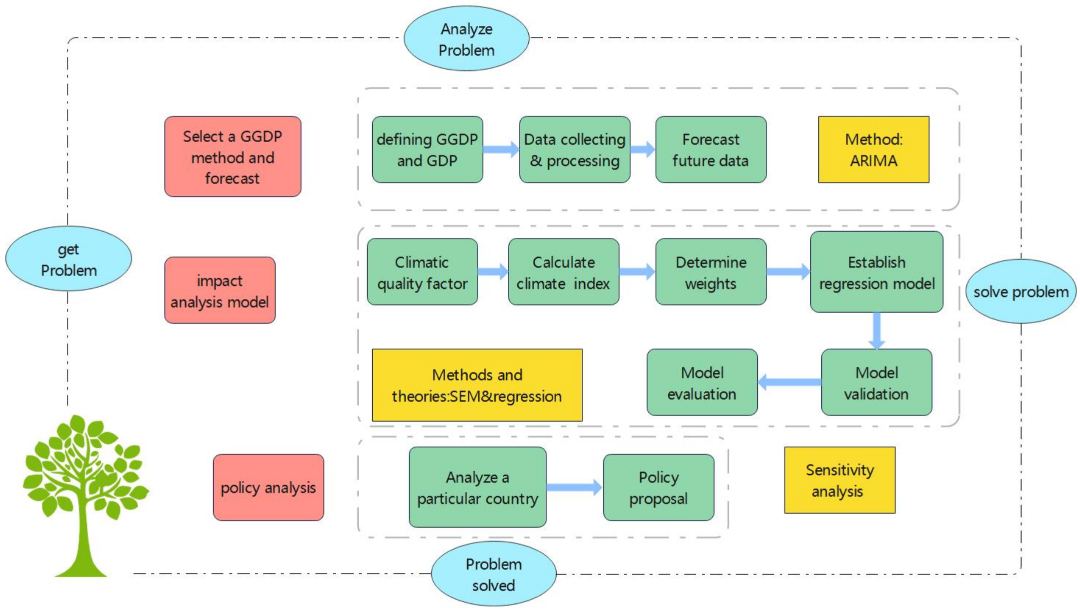


Figure 3 Our work

2 Model Preparation

2.1 ways to calculate GGDP

GGDP is broadly defined as GDP based on the deduction of external uneconomic factors such as resource depletion and environmental pollution, and plus external economic factors such as underground economic activities and leisure activities.

The first thing is to choose a way to calculate GGDP, which is actually a derivative of the concept of "deduction of natural capital consumption from GDP". Some of the common methods to calculate GGDP include: Green GDP Index (**GGDPI**), Ecological Gross Domestic Product (**EDP**) and Climate Mitigation Weighted Gross Domestic Product (**CWCGDP**).

In this paper, we use the indicators given in "National Green GDP Assessment and Prediction for China Based on a CA-Markov Land Use Simulation Model" based on the System of Environmental Economic Accounting (**SEEA**) for reference, and GGDP is defined as follows:Green GDP = Tradition GDP - (Environmental pollution cost+Resource depletion cost)+Environmental improvement cost

$$\text{Green GDP} = \text{Traditional GDP} - \begin{array}{c}(\text{Environmental pollution cost} + \text{Resource depletion cost}) \\ + \text{Environmental improvement cost}\end{array}$$

The Environmental pollution cost, also known as the cost of environmental degradation, refers to the environmental pollution loss and the cost of protecting the environment. Currently, most of the relevant studies use carbon emission cost to represent environmental cost, which ignores the effect of SO_2 emission cost and the damage caused by water and solid pollution to the environment. Therefore, carbon and SO_2 emissions are chosen to represent the air pollution account, waste water emissions are chosen to represent the water pollution account, and the solid waste emissions and solid waste storage are chosen to represent the solid pollution account to measure the cost of environmental pollution.

Resource depletion cost refers to the value of resources consumed in economic activities. Due to the dependence of economic development on fossil energy and water resources, we choose fossil energy consumption and water resources consumption to measure resource depletion costs. Besides, some scholars have also taken Arable Land Resources into consideration, but considering that it is difficult to find the annual data on the change of Arable Land occupation in each sector, we don’t take it into account.

Environmental improvement costs refer to the positive economic benefits brought by the utilization of waste or the improvement of environmental conditions, including the output value of the comprehensive waste utilization and the ecological benefits of the gardens.

2.2 Assumptions and Justifications

In order to simplify our model analysis process and make the model have a larger scope of application, we make reasonable assumptions for the model and explain the justification for each assumption.

1. The global GDP and the GDP of all countries in the world can be predicted using the time series model, and are not affected by unknown factors such as war and natural disasters.

Justification: Other factors such as war and natural disasters are unpredictable, and considering the impact of these factors on the GDP growth rate will affect our GDP forecast.

2. The indicators we selected can reflect climate mitigation effectively and reasonably

Justification: There are many indicators that can reflect climate mitigation to a certain extent , and different indicators also interact with each other . It is impractical to enumerate all the indicators that affect climate mitigation in detail , and it will also bias the model , so only a limited number of indicators can be selected .

3. Only economic development and time will affect climate quality, ignoring other factors.

Justification: Considering other factors will make our model more complex, so that the impact of the two accounting methods on climate mitigation can be seen more directly.

4. the statistics we collected from the websites are reliable and accurate. We assume that the statistics we collected from the websites are reliable and accurate.

Justification: The data supports the model well. The data we collect comes from authoritative sources such as the United Nations, the World Intellectual Property Organization, the World Bank, and the World Energy Council, which are highly accurate and reliable.

2.3 Notations

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

Table 1: Notations

Symbol	Description
GGDP	Green gross domestic product
GDP	Gross domestic product
AT	Average temperature
APD	Average precipitation in depth
FA	Forest area of land area
CQI	Climate quality index

2.4 Data Pre-processing

We chose a panel of data covering 12 countries from 1990 to 2019. These data cover all continents except Antarctica, including developed and developing countries, ensuring the scientific nature of our analysis and the representativeness of our sample.

The availability of data is a fundamental issue. We cannot effectively assess the extent of global equity if the data themselves are unreliable or untrue. It is therefore important to promote continuity and authenticity in the data we obtain. However, some data is missing due to incomplete data disclosure by countries. To solve this problem, we complete our data using the following method:

- If the data is smooth enough, missing data can be replaced with data before and after the data.
- If two sets of data are similar, the missing data in one set can be replaced with a value in the same place in the other set.
- If the data before and after the missing value is available, take their average to fill in the missing value.

3 Establish Auto-regressive Integrated Moving Average Model

$ARIMA(p,d,q)$ model (Auto-regressive Integrated Moving Average Model) can not only analyze smooth time series data, but also differential process the data satisfying the root process of d order unit, and convert it into smooth time series before modeling. model should meet the following requirements:

1. Smooth data meet the following three conditions：
   - The mean is fixed constant：$E(x_t) = E(x_{t-s}) = u$
   - Variance is present and is constant：$var(x_t) = var(x_{t-s}) = \sigma^2$
   - Covariance is only related to the interval s, not to t: $cov(x_t, x_{t-s}) = \gamma_s$
2. The white-noise sequence satisfies the following conditions:

- The overall auto-correlation coefficient: $\rho_s = \begin{cases} 1, S = 0 \\ 0, S = 1 \end{cases}$
- Sample auto-correlation coefficient: $\hat{\rho}_s = \frac{\sum_{t=s+1}^{T}(x_t-\bar{x})(x_{t-s}-\bar{x})}{\sum_{t=1}^{T}(x_t-\bar{x})^2}$

3.1 GDP forecast

1. Time series diagram analysis

The following figure shows the timing diagram of the sample data. As can be seen from the figure, except for the small decline in global GDP in 2008 and 2014, the global GDP basically showed a stable upward trend in other years.

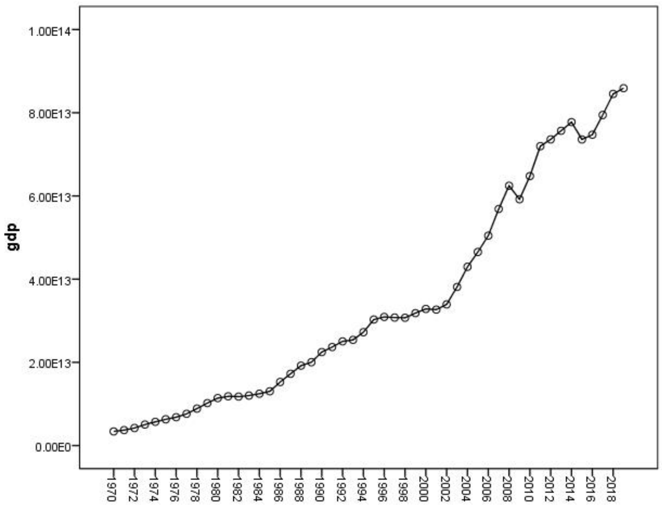


Figure 4 GDP sequence chart

2. Model building and solution

The $ARIMA(p,d,q)$ model formula is as follows , where d means d order difference, $\sum_{i=1}^{p}\alpha_i L^i = AR(p)$ is p order auto-regressive model , $\sum_{i=1}^{q}\beta_i L^i = MA(q)$ is the p order moving average process.

$$y_t^{'} = \alpha_0 + \sum_{i=1}^{p}\alpha_i y'_{t-i} + \varepsilon_t + \sum_{i=1}^{q}\beta_i\varepsilon_{t-i} \tag{1}$$

$$y_t^{'} = \Delta^d y_t = (1-L)^d y_t \tag{2}$$

$$\left(1-\sum_{i=1}^{p}\alpha_i L^i\right)(1-L)^d y_t = \alpha_0 + (1+\sum_{i=1}^{q}\beta_i L^i)\,\varepsilon_t \tag{3}$$

Using the SPSS24 time series model prediction function, we found that the increasing trend of global GDP between 1970 and 2019 fits with the $ARIMA(p,d,q)$ model，$d=1$，$\sum_{i=1}^{p}\alpha_i L^i = \sum_{i=1}^{q}\beta_i L^i = 0$，So the dependent variable satisfies:

$$(1-L)y_t = \alpha_0 + \varepsilon_t \tag{4}$$

Simplified:

$$y_t = \alpha_0 + y_{t-1} + \varepsilon_t \tag{5}$$

$\alpha_0 = 1.684 \times 10^{12}$, The R^2 of the model was 0.993, fitting the model. As shown in the figure below, the fine red line represents the measured values, the thin blue line represents the fitted values, the thick blue line represents the predicted values, and the measured and fitted values basically coincide.

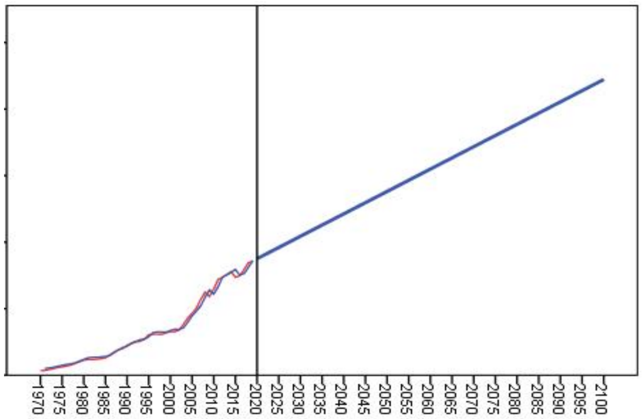


Figure 5 Fitting graph

3. White noise test for the residuals

After the completion of the time series model, white noise is required to test the residual. If the residual is white noise, it means that our model can fully identify the law of the time series data, that is, the model is acceptable; if the residual is not white noise, it means that some information is not recognized by the model, and the model is modified to identify this part of the information.

In addition to the ACF auto-correlation coefficient map and PACF partial correlation coefficient map, the Q test proposed by Ljung and Box in 1978 can also help us determine whether the residual is white noise:

$$\begin{cases} H_0: \rho_1 = \rho_2 = \ldots = \rho_s \\ H_1: \rho_i \, (i = 1, 2 \ldots s) \quad at\ least\ one\ is\ not\ 0 \end{cases} \tag{6}$$

Under the condition that H=0, the statistic

$$Q = T(T+2) \sum_{k=1}^{s} \frac{{r_k}^2}{T-k} \sim {X^2}_{s-n} \tag{7}$$

T is the number of samples, n is the number of unknown parameters, and s can be taken 8, 16, 24, etc. according to the sample size; If the p-value is less than 0.05, the null hypothesis is rejected, and the model is not fully recognized and needs to be corrected.

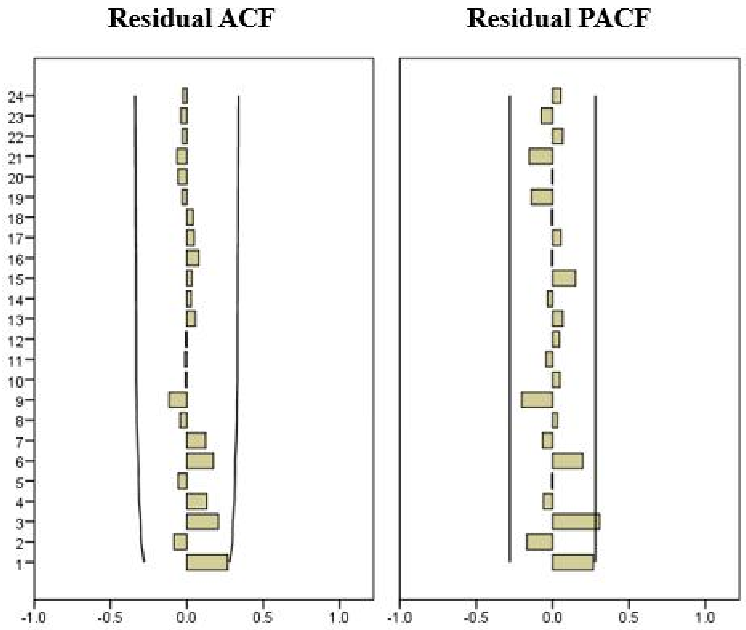


Figure 6 GDP residual test chart

Firstly, from the residual test plot, it turns out that the residuals do not go beyond the boundary, that is, there is no significant difference between the residuals and 0. Secondly, the significance of the Q statistic is 0.831, which is greater than 0.05, indicating that the model we selected can identify the law of time series data and does not need further correction.

Table 2: Model statistics

model	R^2	Q statistics	df	significance	outliers
GDP model	1.110E-16	12.314	18	0.831	0

3.2 GGDP forecast

1. Time series diagram analysis

From the figure, it can be seen that the global green GDP and GDP show a similar steady upward trend, and the trend of global green GDP from 1970 to 1984 is relatively flat.

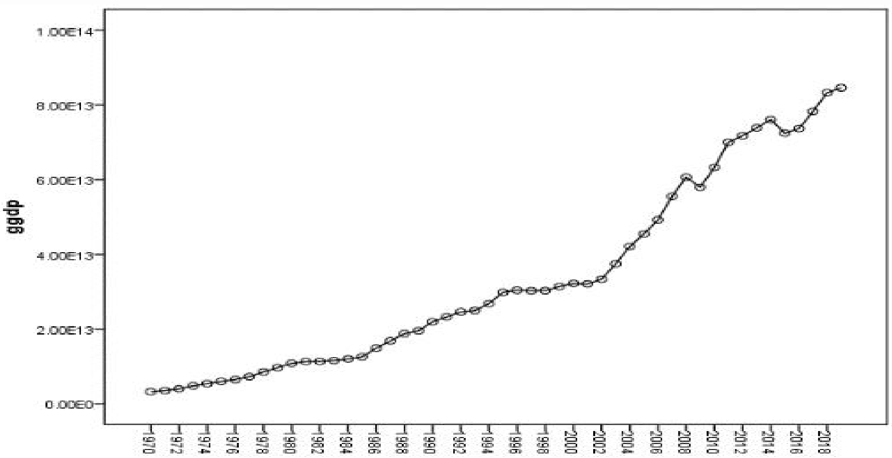


Figure 7 GGDP Sequence diagrams

2. Model establishment and solution

Holt's Linear Trend model applies to series with a linear trend and no seasonality. The smoothing parameters are levels and trends, unconstrained by mutual values, and are very similar to the model. The model contains mainly one forecasting equation and two smoothing equations.

$$\begin{cases} l_t = \alpha x_t + (1-\alpha)(l_{t-1} + b_{t-1}) \\ b_t = \beta(l_t - l_{t-1}) + (1-\beta)b_{t-1} \\ \hat{x}_{t+h} = l_t + hb_t, h = 1,2,\ldots \end{cases} \tag{8}$$

t is the current period, h is the number of over-predicted periods, x_t is the actual observation in t period, l_t is the predicted level at moment t, b_t is the predicted trend at the moment, α is the smoothing parameter for the level, and β is the smoothing parameter for the trend. A time series model with GGDP as the dependent variable finds that the data for global green GDP fits the Holt model with an R^2 of 0.994, a smoothing parameter of 1 for the level, and a smoothing parameter of 0.1 for the trend.

Table 3: Holt's Linear Trend Model Parameters

	Estimate	Std. Error	t	significance
Alpha（level）	1.000	0.145	6.893	0.000
Gamma（trend）	0.100	0.064	1.560	0.125

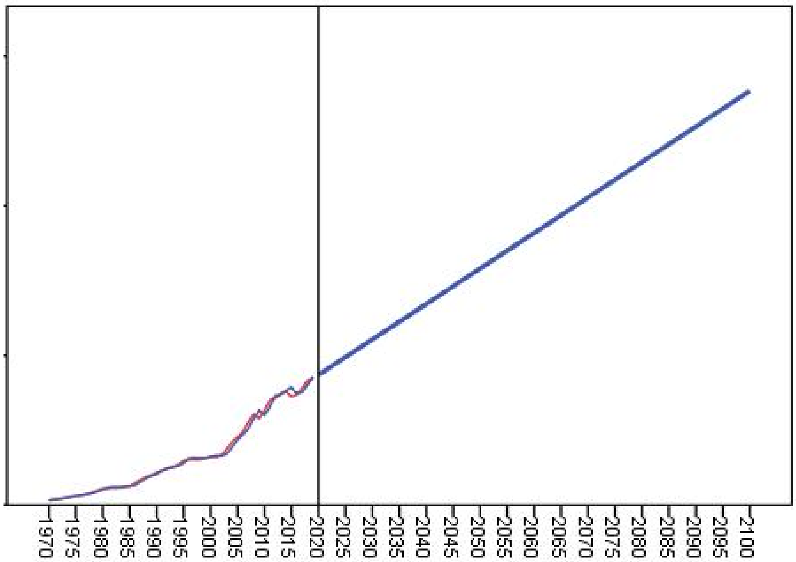


Figure 8 Fitting graph

3. White noise test for the residuals

It turns out that the residuals are not significantly different from 0. The value of the Q statistic obtained from the model statistics table is 16.540 with a significance of 0.416, which is greater than 0.05, indicating that the Holt linear trend model is able to identify patterns in the time series data.

Table 4: Model statistics

model	R^2	Q statistics	df	significance	outliers
GGDP model	0.318	16.540	16	0.416	0

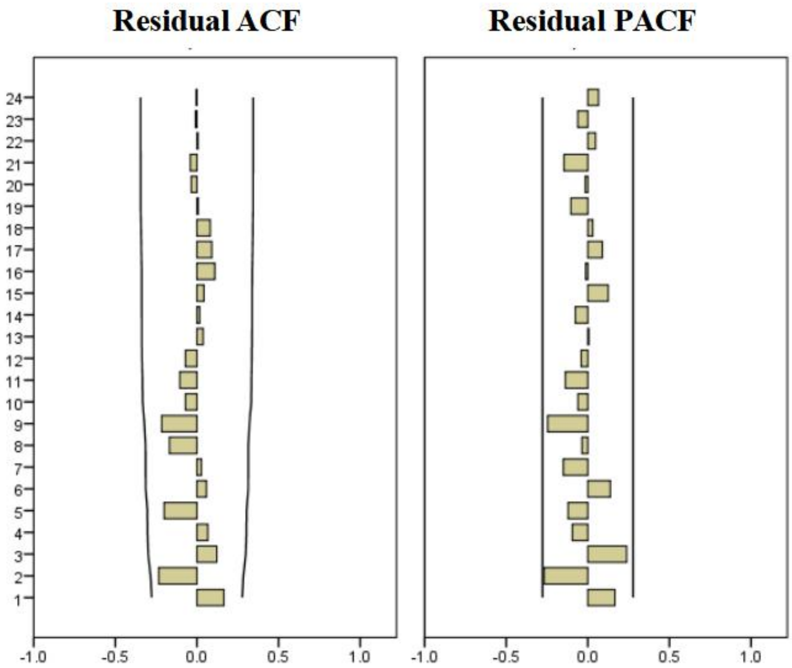


Figure 9 GGDP residual test chart

Entropy Weight Method (EWM) is an objective weighting method. The principle is that the smaller the degree of variation between different data, the more information it reflects, the higher weight will be assigned to it. We calculate the weights of climate index to develop an evaluation model for climate mitigation

First, we normalized the different indicators due to their inconsistent orientation:

4 Establish Evaluation Model

A climate quality measurement index CQ should be established to measure a region's climate quality. And three aspects (temperature, precipitation and air quality) should be included, so we choose four indicators--average temperature, average precipitation depth, forest cover and greenhouse gas emissions--to establish the evaluation system.

4.1 Analyze the Weights for Climate quality by EWM

EWM is a useful weighting method. The principle is that the smaller the degree of variation between different data, the more information it will reflect and the greater the weight will be assigned to it. We calculate the weights of the climate indices to build an evaluation model for climate mitigation. The selected climate indexes are shown in the following table.

Table 5: Notations

Symbols	Description
TGGE	Total greenhouse gas emissions
AT	Average Temperature
APD	Average precipitation in depth
FA	Forest area of land area

At first, we normalize different indicators. Among the selected indicators, TGGE is a cost-based indicator; AT and APD are intermediate-type indicators, so we use different ways to deal with different data:
For cost-based indicators:

$$X_i = \max - X \tag{9}$$

For intermediate-type indicators:

$$X_i^{'} = \frac{x_{\max} - x_i}{x_{\max} - x_{\min}} \tag{10}$$

For interval-type indicators:

$$\begin{cases} 1 - \dfrac{a - x_i}{M}, & x_i < a \\ 1, & a \leqslant x_i \leqslant b \\ 1 - \dfrac{a - x_i}{M}, & x_i > b \end{cases} \tag{11}$$

Next, we can calculate the proportion of p_{ij} the indicator of i_{th} the country:

$$p_{ij} = \frac{v_{ij}}{\sum_{i=1}^{n} v_{ij}} \tag{12}$$

i represents the ordinal number of the 12 countries, j represents the ordinal number of the inferior indicators in each category, v_{ij} means the value of the corresponding indicator, and n represents the number of the countries, which is equal to12 in our model.

The next step is to calculate the information entropy of each indicator and the information utility value, and then normalize them to obtain the entropy weight of each indicator:

$$E_j = -\frac{1}{\ln\ n}\sum_{i=1}^{n}(p_{ij} \times \ln p_{ij}) \tag{13}$$

$$W_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \qquad (j=1,2,...,m) \tag{14}$$

Based on these calculated weights, we have:

CQI=w1* TGGE+w2* AT+w3* APD+w4* FA

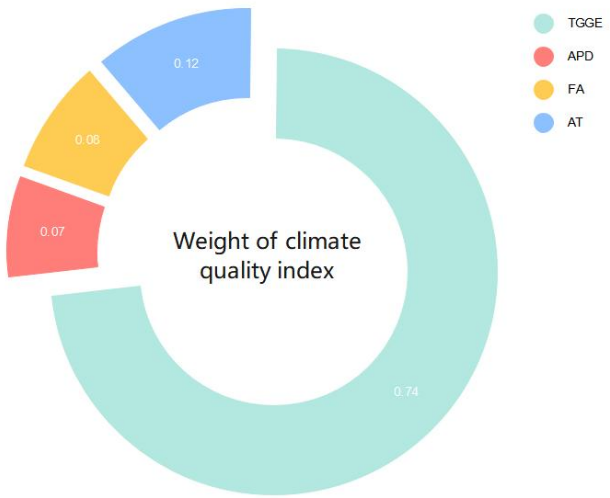


Figure 10 Weight of climate quality index

4.2 The Establishment of Coefficient of variation model

The coefficient of variation method is also a method of objective weighting. Among the indicators, the data changes under some indicators have large differences, and the data changes under some indicators have small differences. The data that has a greater impact on the subject should be the data with large changes, and the corresponding indicators are of higher importance and should be given higher weights. The formula for calculating the coefficient of variation is:

$$cv_i = \frac{SD_i}{\bar{x}_i} \tag{15}$$

SD_i is the standard deviation of a set of data and $\bar{x}_i$ is the mean of a set of data. Then, the calculated weights are:

$$W_{cvj} = \frac{cv_i}{\sum_{i=0}^{n} cv_i} \tag{16}$$

Then we can calculate:

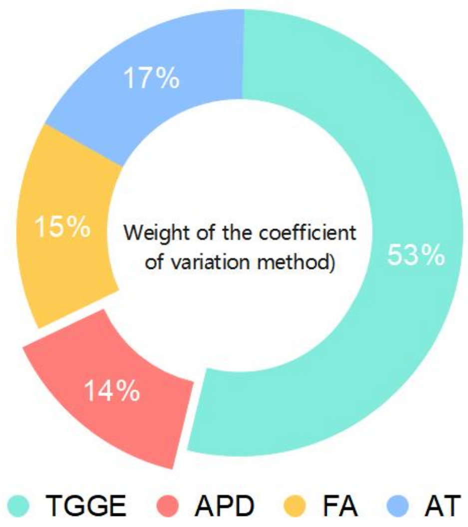


Figure 11 Weight based on the coefficient of variation method

5 Establish Regression Model

Regression model is a mathematical model for quantitative description of statistical relationships. For example, the mathematical model of multiple linear regression can be expressed as y= $\beta_0 + \beta_1 * x + \varepsilon_i$, in which, β_0 , β_1 , ..., β_p are *p+1* parameters to be estimated, ε_i are random variables that are independent of each other and obey the same normal distribution N(0, σ^2), *y* is a random variable; *x* can be a random variable or a non-random variable, β_i is called regression coefficient that characterizes the degree of influence of the independent variable on the dependent variable.

5.1 Establish Regression Model

To effectively get the conclusion of the impact of *GGDP* on global climate mitigation, we build regression models using *GDP* and *GGDP* as independent variables, respectively, and project the climate quality indicators for the next *N* years, comparing the magnitude of *CQ* values, other things stay same, with larger *CQ* values indicating that the accounting method is more effective for climate mitigation.

The model is as follows:

$$CQGDP = \alpha + \beta_1 GDP + \beta_2 T \tag{17}$$

$$CQGGDP = \alpha^* + \beta_1{}^* GGDP + \beta_2{}^* T \tag{18}$$

5.2 Testing and Prediction

Table 6: GGDP

Multiple R	0.975452185
R Square	0.951506965
Adjusted R Square	0.94611885
Std. Error	228.7875909
Observations	21

Table 7: GDP

Multiple R	0.976159656
R Square	0.952887674
Adjusted R Square	0.947652971
Std. Error	225.5070146
Observations	21

From the data in the table, the decidable coefficients of the two regression equations, R^2, are larger, indicating that the closer the model regression line is to the observed values, the better the model fit is.

Table 8: Significance test

	Coefficients	**Std. Error**	**t Stat**	**P-value**
GGDP	1.67408E-11	1.14E-11	2.462483305	0.090850273
	Coefficients	**Std. Error**	**t Stat**	**P-value**
GDP	1.28222E-11	1.02E-11	2.251182444	0.096886088

GDP and GGDP have larger t-values and pass the significance test at a significance level of 85%

The Fit test and t-test indicate that the model is set up reasonably and GDP and GGDP can represent the climate mitigation index better.

With the regression model prediction, GGDP and GDP are used as economic development indicators, respectively, to predict the climate quality index for the next N years, and the results are shown in the following graph:

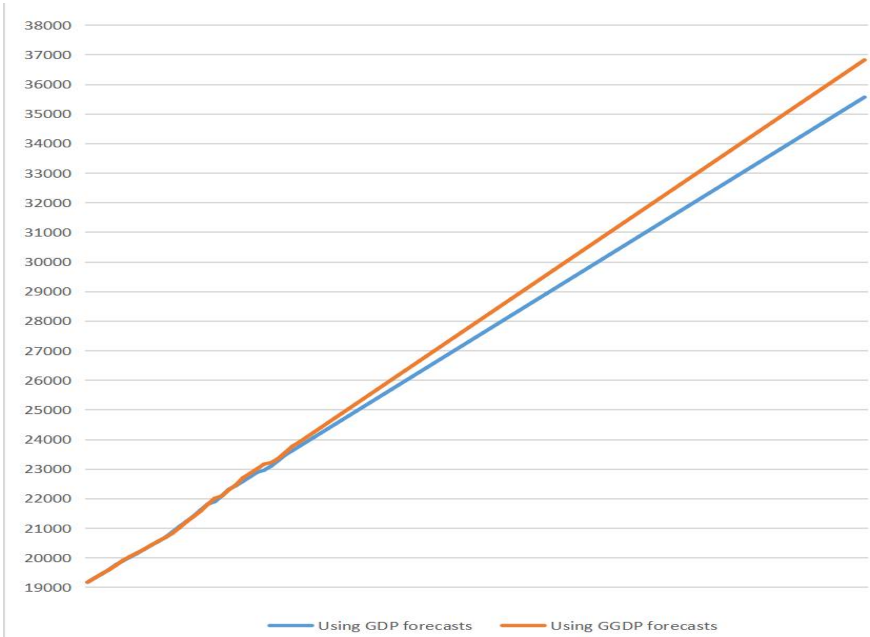


Figure 12 Forecast map of climate indicators

In the short term, the difference between GDP and GGDP on climate quality is not significant, and the effect of using GDP and GGDP to account for economic levels on global climate mitigation is small. However, in the long term, using GGDP to account for economic climate quality indicators is significantly greater than GDP, indicating that using GGDP to account for the economy can improve environmental quality in the long term.

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.735	0.735	13.036	0.000
		2	0.424	-0.252	17.600	0.000
		3	0.106	-0.229	17.901	0.000
		4	0.026	0.296	17.920	0.001
		5	0.004	-0.080	17.920	0.003
		6	-0.014	-0.169	17.927	0.006
		7	-0.028	0.144	17.953	0.012
		8	-0.035	-0.011	18.000	0.021
		9	-0.029	-0.095	18.035	0.035
		10	-0.039	0.015	18.103	0.053
		11	-0.062	-0.025	18.287	0.075
		12	-0.113	-0.135	18.969	0.089

Figure 13 Stability test

6 Global impact analysis

6.1 The potential upside of climate mitigation impact

- Beneficial to the sustainability of economic development

Green GDP, through the rational coordination of capital and resources, can optimize the allocation of resources and actively cultivate innovation and competitiveness. Besides, green GDP focuses on development in the "time dimension", which is conducive to judging the long-term rationality of a country in the development process.

- Beneficial to environment

Green GDP can measure the "development degree" of a country or a region and it helps the country to develop in a healthy way, to develop rationally and create a comfortable living space for human beings

- Beneficial to human health

Green GDP can contribute to the creation of a green and healthy environment, thus improving the level of ecological services and environmental support of a country or region.

- Beneficial to social equity

A harmonious, stable and safe human environment is a prerequisite for economic development and social progress. Since the environment is a natural resource that is free to be shared, it can overcome the differences between the rich and the poor and between urban and rural areas, and achieve interpersonal, inter-generational and inter-regional equity in resource sharing.

- Beneficial to national stability

social stability is the foundation to maintain the orderly operation of the "national system". Under sustainable development, a country or a region can "build social values, maintain social order, improve social resistance, and improve social moral constraints", which will become a support for macro-control and governance.

6.2 The potential downside of climate mitigation impact

- Imprecision caused by standards and data

So far, there is no international standard on how to adjust traditional GDP indicators to form green GDP. Moreover, green GDP accounting is difficult because of the inherent problems in assessing and quantifying the costs of natural resource consumption and ecological damage.

- Creating non-essential competition among countries

The concept of green GDP is vulnerable to serious criticism when dealing with pragmatic issues. How do you compare social indicators depending on how you attribute values to different factors, you can actually get any ranking you want.

- Loss of GDP

In order to beautify the GGDP statistic or to improve the environment, sometimes we are forced to shut down some high-pollution companies, and sometimes we have to spend lots of money in purify the rivers and the air. Those both have negative impact on the economy.

7 Country-specific analysis

7.1 How GDP and GGDP are calculated

The common method of GDP accounting is the expenditure method: it measures the final results of production activities of all resident units during the accounting period from the point of view of the end use of goods and services, and includes three parts: final consumption expenditure, gross capital formation, and net exports of goods and services, but excludes depreciation of manufacturing assets and depletion of natural resources.

$$Y = C + I + X - M \tag{19}$$

Y is gross national product, C is consumption expenditure, I is capital, X is exports of goods and services, and M is imports of goods and services.

GGDP attempts to integrate economic, political, social and environmental factors on the basis of GDP to reveal potential synergies, trade-offs and futurity. In order to avoid the assessment of green economy, which is influenced by subjective reasoning, scholars have established a number of statistical data-based measures, one of which is widely recognized as a comprehensive measure as follows:

$$GGDP = GDP - (KtCO_2 * PCDM) - (Twaste * 74kWh * Pelect) - (\frac{GNI}{100} * \%NRD) \quad (20)$$

$KtCO_2$ is carbon dioxide emissions expressed in thousands of tons, ***PCDM*** represents the average weighted carbon price in ***PPP***, ***Twaste*** is the weight of waste, ***74kWh*** represents that 1 kiloton of waste generates about 74 kWh of energy, ***Pelect*** is the purchasing power parity price per kWh, ***GNI*** is gross national income, and ***% NRD*** is the quantified natural resource consumption as a percentage of gross national income.

7.2 Country Development Background

- Industrial structure and pollution

On the whole, China's manufacturing industry has obvious overcapacity in the traditional manufacturing industries such as steel, coal, cement and other industries in the industrial chain, while high technology products such as satellite space, large numerical control equipment and chips are heavily dependent on imports, forming a total surplus of labor and capital-intensive products and a shortage of technology-intensive products. In addition, China's long-established trade model make the country in the world's industrial chain at the low end with industrial upgrading difficulties. The more prominent high pollution enterprises in China's industrial system are as follows.

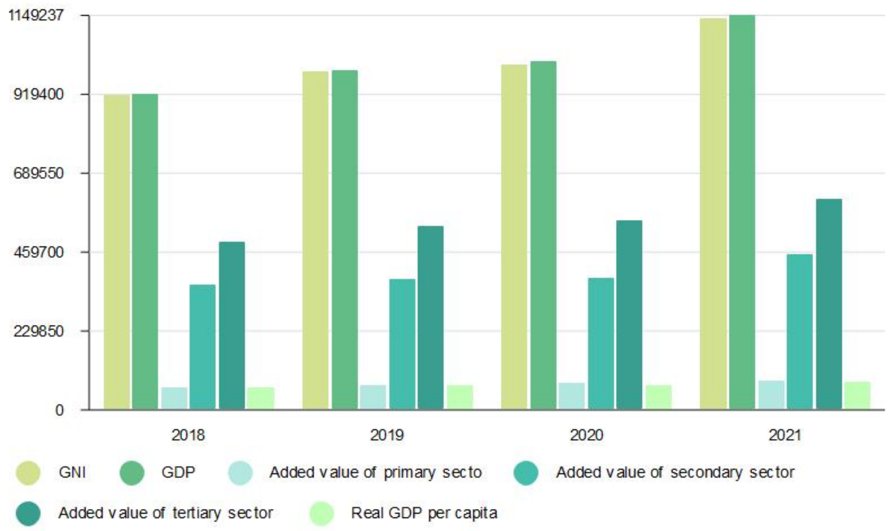


Figure 14 Prominent high pollution enterprises in China's industrial system

- Future Income

In the post-epidemic period, the global economy has become more fragile, global value chains are facing more drastic adjustments, global debt has reached new highs, global macroeconomic governance has entered uncharted territory, and social distribution shows a trend of continued widening of income disparities. In this context, the potential growth rate of China's economy is changing from the rapid growth rate of the past decade to a stable medium-high growth rate, with an average potential growth rate of 5.7% in the next five years.

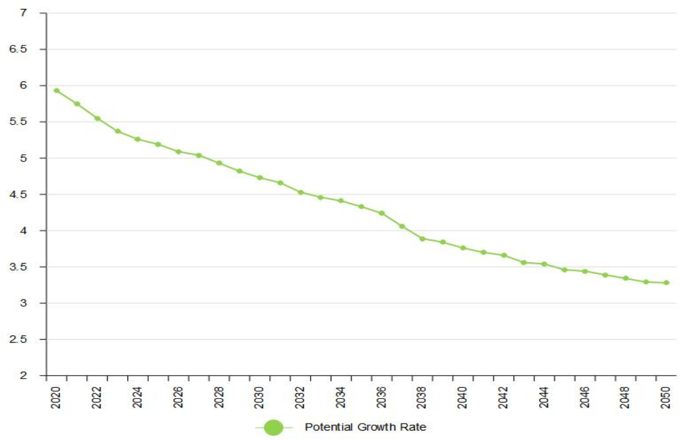


Figure 15 2020-2050 China Potential Growth Forecast (%)

- Low-Carbon Technologies

Low-carbon technologies can be divided into three categories: environmental technologies, energy-saving technologies and decarbonization technologies. Among these technologies, environmental technologies are relatively easy to implement and have a wide range of applications. According to a survey by China's National Bureau of Statistics, China has abundant renewable energy resources. The exploitable hydropower resources can be developed at least 378 million kilowatts; geothermal resources reserves about 462.6 billion standard coal equivalent (SCE); exploitable tidal energy to be developed is more than 20 million kilowatts; wind energy resources may reach 1.6 billion kilowatts In total, renewable energy and other new energy resources are abundant enough for China's economic development. However, China lacks competitive R&D institutions and high-quality patents for low-carbon technologies compared to developed countries.

7.3 Recommendations for the use of natural resources

The first reason for environmental improvement is the carbon intensity achieved through technological innovation, and the second one is the loss of GDP in the pursuit of green growth. There is a conflict between economic growth and environmental protection, and controlling carbon emissions will lead to a loss of GDP. As shown in the graph below, China's GDP loss rate, although on a decreasing trend, was still as high as 7.12% until 2016.

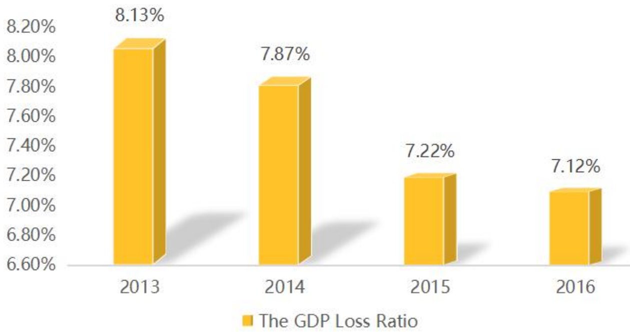


Figure 16 The GDP Loss Ratio

Considering China's future economic growth slowdown, it makes sense to construct a technology and capital sharing mechanism to mitigate the impact of green growth on GDP. Technological innovation, as a key driver of economic growth, not only provides a new growth equilibrium for the current economic growth dilemma, but also provides a new solution to the current resource and environmental problems. If wind and solar power can make revolutionary progress, it will significantly solve the carbon emission problem and significantly mitigate global climate change. Provide incentives for technology transfer. There is already a successful precedent for sharing energy-efficient technologies among global companies, in January the World Business Council for Sustainable Development created the Eco-Patent Commons. The purpose of the Eco-Patent Commons is to accelerate and promote environmental protection by sharing innovations and solutions (Hall and Helmers, 2013). This initiative allows third parties to freely use these technologies to protect the environment. Furthermore, in terms of funding, the externalities of carbon emissions dictate that the main driver of financial support is regional intergovernmental cooperation. Therefore, there is a need for a unified arrangement that allows for coordination between the eastern and western regions of China, the developed and developing countries of the world in terms of carbon emission reduction by referring to the CDM and prioritizing the role of market mechanisms.

8 Sensitivity Analysis

Sensitivity analysis is used to test the stability of the results. In sensitivity analysis, one or more parameters vary within a reasonable range. At the same time, we could record and calculate the changes in the corresponding results. For the sake of checking whether our model are sensitive to changes of the input parameters, we need to carry out the sensitivity analysis. In reality, data often fluctuate due to human error or unpredictable factors. In order to analyze the stability of the entropy model in case of inaccuracies or fluctuations, we can use sensitivity analysis.

To simulate the fluctuation of the data, the variance of the normalized indicator χ_i is calculated. It turns out that the variance of TGGE is the largest. Therefore, a random disturbance term ε_i is added to the TGGE data. And we also assume that the random disturbance fluctuates randomly within 10% of the theoretical data. Since the normalized data is located in the interval [0,1], the data is defined after adding the random disturbance:

$$0.9\tilde{\chi}_i + \varepsilon_i \tag{21}$$

ε_i is a random number in the interval [0,0.1] generated by MATLAB.

Then, new data is used to calculate the weights of different independent variables with the entropy weighting method. By comparing the weights with and without random disturbances, it is easy for us to find out that the weights vary within 1%, and this figure indicates that the weights obtained by TGGE are not significantly affected by external factors, which means our model is relatively stable.

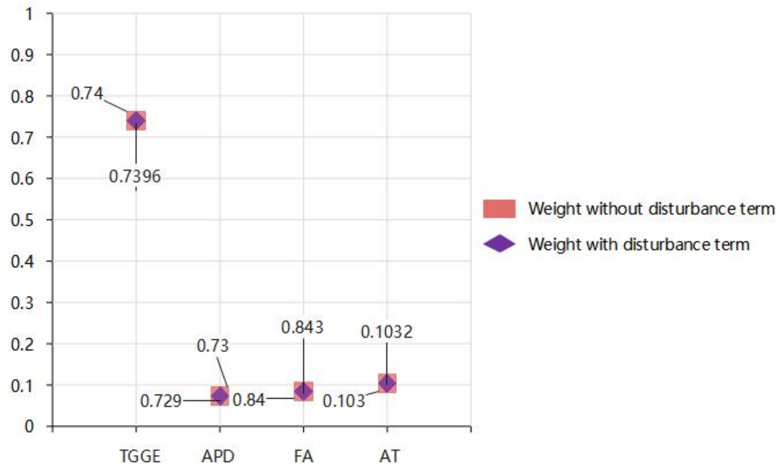


Figure 17 Weight with and without disturbance term

9 Model Evaluation

9.1 Strengths

1. Our model uses 29 years of data from 12 countries as a predictive sample, the data coverage is wide, the time span is long, and the preprocessing is scientific, making our findings more credible.
2. In establishing climate models, we take into account factors from multiple angles, including temperature, humidity and precipitation, so as to establish climate evaluation indicators in a more comprehensive way. It also reflects the rigor of our model.
3. We combine the advantages of various GGDP calculation methods to achieve diversity while ensuring the objectivity of the model.
4. Each indicator we choose can be collected from authoritative data sources like the United Nations, the World Bank and the Chinese Bureau of Statistics to ensure the accuracy.
5. When we build and solve the model, we carry out the level test and time series test respectively, which improves the rigor of our model.
6. We use the combined weight of entropy weight method and coefficient of variation method as the weight of the index to avoid the possible equilibrium defect. The sensitivity test results show that our combined weight preference coefficient has good stability.

9.2 Weaknesses

1. To simplify the analysis process, our model does not consider the impact of the contingency on GDP and climate quality.
2. Due to the limited time and capacity, there is room for improvement in our indicator selection, and some indicators can also be replaced with more appropriate indicators.
3. Climate quality is a complex indicator, and to better compare the impact of GDP and GGDP on climate, we only considered the impact of economic development factors on climate.

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SWITCH TO GREEN GDP

As the world's largest developing country, China has made great contributions to global politics, economy, and environmental governance, especially in energy conservation and emission reduction, and has made a lot of efforts to promote carbon trading. However, it is undeniable that China's manufacturing structure is still unbalanced, and the proportion of heavy industries and processing manufacturing industries that pollute the environment at the cost of pollution is still large, and there is a need to make some further improvements.

Based on the time series predictive model, we select the indicators that have a significant impact on the ecological environment by the entropy method and construct the climate index as the dependent variable, and then construct two regression models with GNP and green GNP as the independent variables.

The findings show that in the short term, the differences in the effects of GDP and GGDP on environmental quality (including greenhouse gas emissions, average temperature, precipitation, and forest cover) are not significant, and the effects of using GDP to account for development levels and using GGDP to account for development levels on global climate mitigation are not significant. However, in the long term, the global climate quality indicators are significantly higher after adopting the GGDP-accounted development level than the climate quality when using the GDP-accounted development level, indicating that in the long term, using the GGDP-accounted development level can improve environmental quality.

Faced with the contradiction between the economy and the environment, China should focus its development on low-carbon technology, especially environmental technology.

On the one hand, China's vast territory is rich in solar, natural gas, wind, and other resources, and the development of new energy technologies can not only protect the environment but also reduce energy costs.

On the other hand, China can actively promote the ecological aspects of the global capital and technology sharing mechanism, the global developed countries and developing countries the degree of pollution and ecological technology research and development there is a large gap, developing countries are far less ecological patents than developed countries, but at the same time, because of the transfer of industries from developed countries, more high-polluting enterprises, high degree of pollution, in the ecological aspects of the establishment of capital and technology sharing mechanism The establishment of a capital and technology sharing mechanism in ecology is beneficial for developing countries to learn advanced environmental protection technologies and have sufficient funds to deal with environmental pollution caused by the industrial transfer.