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Adaptation and Feasibility Study of Green GDP Accounting System in China

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Abstract: ***In recent years, with the increasing risk of global climate change, the worldwide discussion on green economy has been further intensified. In this paper, based on the central framework of SEEA, we analyze the impact of the environment on the economy from multiple perspectives and establish a green GDP accounting model. In addition, a new method combining random forest regression as well as CRITIC weighting method is used to select reasonable indicators. The accounting formula derived from this new method is used to calculate the green GDP in 2000, 2005, 2010, 2015, and 2020, and to compare the differential contribution of GGDP and GDP of the selected countries to measure the efforts made by each country for environmental protection, and the results show that it is worthwhile to adopt GGDP. This paper focuses on China as the main target for the case study and finds the strongest link between GGDP and clean energy among the indicators. The impact generated by GGDP is also discussed using the gray prediction method. Finally, a statistical approach is used to visualize the growth rate of the aging population, and it is found that the implementation of GGDP is beneficial to the environment, the economy, and the lives of citizens.***

Keywords: SEEA-CF; Random Forest Regression Model; Gray Prediction Model; GGDP; CRITIC Weighting Method**.**

1. Introduction

Gross Domestic Product (GDP) is widely regarded as the best measure of regional economic performance, but it does not take into account resource depletion and environmental damage caused by development. With the large-scale development of industrial production, a large amount of fossil energy is used, and waste water and gas are discharged into the natural environment. Severe environmental pollution provokes a certain degree of negative impact on the residents' quality of life.

In 1993, SEEA 1993 formally introduced the concept of green GDP, and SEEA 2003 referred to the adjustment of resource depletion, environmental degradation and environmental expenditures of economic aggregates as green GDF accounting. Maile (1991) pointed out that green GDP is an accounting method designed to measure welfare. The Sustainable Development Research Group of the Chinese Academy of Sciences (1999) proposed that green GDP = traditional GDP - dummy for the natural component - dummy for the human component. Boycl (2006) defined green GDP as accounting for the natural values not included in GDP. Yang Maengkun (2007, 2008) points out that GDP accounting only reflects positive utility and ignores negative utility, which cannot reflect the national welfare truly enjoyed by the whole society, and proposes gross national welfare (GNW), which is the net impact of positive and negative utility of economic activities on the material and spiritual life of human beings, and regards GNW as green GDP in a broad sense. Wang Jinnan (2018) considers green GDP as the GDP basis by deducting the cost of loss of environmental pollution and the cost of loss of ecological damage due to unreasonable human use. The Research Report on China's Environmental Economic Accounting 2005-2006 proposes that green GDP is the GDP that deducts the cost of resource consumption and environmental pollution. In 2004, the National Bureau of Statistics and the State Environmental Protection Administration of China (SEPA) adopted two reports, "Framework of Environment-based Green National Economic Accounting System" and "Framework of China's Environmental Economic Accounting System", which laid the theoretical foundation for the implementation of green GDP accounting system in China.

Starting with the pioneering work of Daly et al. (1989), there have been several attempts to develop alternative systems of national income accounting (which is commonly referred to as "green" GDP) to address the shortcomings of the traditional GDP accounting system. Recent scholars have argued that Green GDP is another indicator of economic growth that incorporates the impact of economic growth on the environment, including the depletion of natural resources and environmental degradation (Stjepanović, S., Tomić and D. et al. 2019). An attempt is made to construct a Chinese green GDP accounting system based on a resource and environmental perspective, which is found to reflect the benefits resulting from better ecological quality and environment (Cai 2022). A greater link between energy and green GDP has now been confirmed (ŠKARE and M. 2020).

China's agroecosystem is characterized by a profound transition from a subsistence tradition to a modern industry based on the consumption of external economic resources (Hu, J.and Lyu et al. 2022). As the largest developing country, China faces increasing environmental and resource constraints on its economic development, and the construction of ecological civilization is receiving increasing attention. For better development, it is necessary to create a new synergy between economic and environmental concepts, so the implementation of a green GDP accounting system should be seen as an opportunity rather than an obstacle to equitable and sustainable growth/development prospects (Stjepanović and S. et al. 2017). In order to study the impact of different characteristics of developing and developed countries on the establishment of a green GDP accounting system, this paper obtains relevant data from Mexico and the United States (which have implemented a green GDP accounting system) for further study.

2. Methodology and data

2.1 Method of Green GDP accounting

Comprehensive macro-accounting of the interaction between the economy and the environment and changes in the state of the environment is called environmental economic accounting. The Earth Summit in 1992 and its message of sustainable development stimulated the launch of the System of Integrated Environmental and Economic Accounting (SEEA). Since then, sustainable development and SEEA gave way to green growth and green economy indicators at the recent 2012 summit. And the central framework (SEEA-2012) is adopted by the Statistical Commission in 2012 as a new international standard that continues today. The accounting focus of the SEEA-CF (central frame) can be discussed in three perspectives: Physical flow of material and energy within the economic system and between economy and environment; Economic activities and transactions related to the environment; Environmental asset stock and its change.

In order to comprehensively assess the health of a nation's economic development, environmental factors are added to the original GDP. As shown in Table 1, based on SEEA, this paper considers the impact of environmental factors from three aspects and set up three indexs (the rectification cost of environmental degradation (RCED), the cost of natural resource consumption (CNRC) and the amount of green economy (AGE)) to establish the GGDP model (**Table 1**). Among them, RCED can be divided into wastewater treatment and waste gas treatment, CNRC can be divided into energy, land and forest cover area, and AGE can be divided into solar energy, wind energy and hydropower. In order to avoid the impact of short-term fluctuations and other events on the accuracy of data, and reflect the long-term trend of economic development, then calculate the GGDP values of 2000, 2005, 2010, 2015 and 2020 at 5-year intervals, and analyze their possible impacts.

Ultimately, the latest System of Environmental-Economic Accounting-2012 (SEEA-2012) is chosen for this paper. The main steps of using this system in environmental resource accounting are the calculation of RCED, CNRC and AGE.

Table 1: The indices of 3 dimensions

Resource Type	Specific categories	Feedback
RCED	Wastewater treatment	-
	Exhaust gas treatment	-
CNRC	Energy	-
	Land	-
	Forest	-
AGE	Solar Power	+
	Wind energy generation	+
	Hydroelectricity	+

In the table above, the effect "+" is the benefit-type index (the larger, the better). The effect "-" is the cost-type index (the smaller, the better) while the effect "*" is the moderate-type (the closer to one exact value, the better).

RCED represents the cost of a country to control pollutants over a period of time. It can be divided into two parts: the cost of water pollution control and air pollution control.

$$C_{RCED} = \sum_{i=1}^{n} (Q_i * P_i) \quad (1)$$

where Q_i indicates the total amount of part i to be governed, and P_i indicates the market unit price of Part i governed.

CNRC represents the value of natural resources consumed by a country over a period of time. It can be divided into three aspects: forest resource consumption, land resource consumption and energy consumption.

$$C_{CNRC} = \sum_{j=1}^{n} (Q_j * P_j) \quad (2)$$

Q_j is the total consumption of part j natural resources, and P_j is the market unit price of part j natural resources.

AGE refers to the economic benefits a country gains from renewable energy over a period of time. Then calculate AGE in terms of wind power, solar power and hydroelectric power.

$$C_{AGE} = P_E * \sum_{k=1}^{n} E_k \quad (3)`$$

E_k is the total amount of part k renewable energy generation and P_E is the market unit price of electricity.

When accounting for green GDP, how national economic activities affect the environment is the main point of consideration, and these impacts include accounting for natural resource consumption and environmental pollution degradation. As presented in **Table 2**, this paper argues that in accounting for green GDP, it is necessary to account for the rectification cost of environmental degradation (RCED), the cost of natural resource consumption (CNRC), and the amount of green economy (AGE), because these factors reflect the actual gross national wealth of a country or a region. In this thesis, green GDP is calculated mainly from the RCED, the CNRC and the AGE, so that these three aspects can be used to adjust the gross product of the selected country and thus obtain the model of green GDP accounting system.

Table 2: Calculation method of GGDP accounting items

Serial number	Projects	Calculation formula
①	Gross National Product(GDP)	①
②	Accounting formula for RCED	②
③	Accounting formula for CNRC	③
④	Accounting formula for AGE	④
⑤	GGDP adjusted for resource factors	①−③
⑥	GGDP adjusted for environmental factors	①−②
⑦	GGDP adjusted for eco-efficiency factors	①−②−③+④

Above all, GGDP can be expressed as:
$GGDP = GDP - C_{RCED} - C_{CNRC} + C_{AGE}$

2.2 Correlation Analysis

This paper can explore the relationship between five factors (population, carbon dioxide emissions, forest coverage, non-renewable energy resource and annual mean temperature) and GGDP by calculating the correlation between them. The correlation coefficient can be calculated by the following formula.

$$\rho_{X,Y} = \frac{\sum_{i}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i}^{n}(X_i - \bar{X})^2 \sum_{i}^{n}(Y_i - \bar{Y})^2}} \tag{4}$$

According to the calculated correlation results (**Fig. 1**), it can be found that the population, carbon dioxide emissions, forest coverage, and the non-renewable energy resource have a higher correlation with GGDP, while annual mean temperature has a lower correlation with GGDP. Therefore, we believe that there is some connection between these factors and GGDP. The chart shows the correlation between these factors in China.

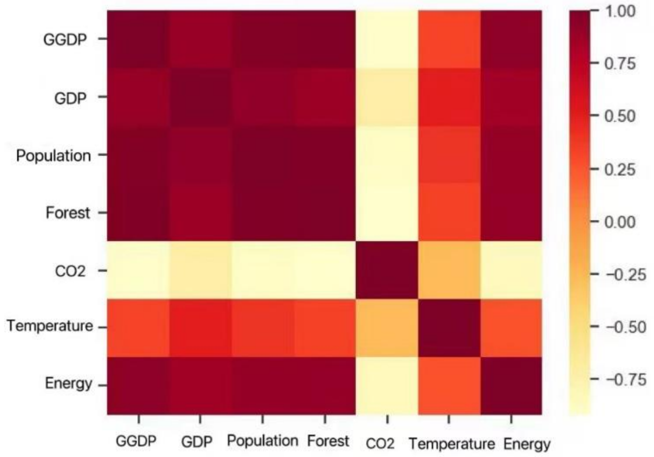

Fig. 1: The correlation between various factors in China

2.3 Random Forest Regression Model

Among various machine learning algorithms, the emerging Random Forest (RF) algorithm was proposed by Leo Breiman and Cutler Adele in 2001 and is considered one of the most accurate prediction methods for classification and regression. For example, combining plant indices and random forest regression algorithms can improve the prediction accuracy of wheat biomass (Zhou et al. 2016). In machine learning, a random forest is a classifier containing multiple decision trees, and its output category is determined by the mode of the categories output by individual trees. It can produce a classifier with high accuracy and maintain accuracy even when most of the data is lost.

In this paper, the data of five factors (population, carbon dioxide emissions, forest coverage, non-renewable energy resource and annual mean temperature) for two types of countries (developed and developing countries) for the period of 2000-2020 are selected to fit GGDP. It is found that their R^2 values are in the range of [0.80,0.95], which indicates a good fit. The R^2 fitted to the data for China is 0.93 and that for the U.S. is 0.89. Therefore, this paper concludes that these five factors explain GGDP well, indicating that GGDP can reflect the environmental conditions. And relatively speaking, these five factors have better explanations for GGDP in China.

2.4 Sensitivity Analysis

Carbon dioxide is an important index to measure the sustainable development of ecological environment. Carbon dioxide is increasing in the atmosphere and is of considerable concern in global climate change because of the warming effect of greenhouse gases. At the same time, it can also be used to compare the environmental conditions of a country when GDP and GGDP are taken as national economic indicators respectively. So there is a three-dimensional scatter plot below to analyze the relationship between the three.

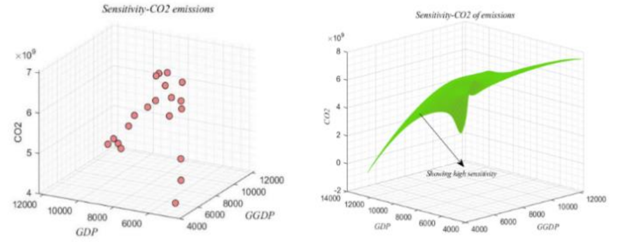

Fig. 2: Sensitivity analysis of carbon dioxide emissions

It can be clearly seen from **Fig. 2** that these points do not aggregate, indicating that the sensitivity of carbon dioxide emissions to GDP and GGDP is very large.

2.4 Grey Prediction Model

Grey Prediction carries out correlation analysis by identifying the different degree of development trend among system factors. Generate and process the original data to find the law of system change and generate data series with strong regularity. Then the corresponding differential equation model is established to predict the future development trend of things.

(i) Let the time series $X^{(0)}$ have n observations, $X^{(0)} = \{X^{(0)}(1), X^{(0)}(2), ..., X^{(0)}(n)\}$, a new sequence $X^{(1)} = \{X^{(1)}(1), X^{(1)}(2), ... , X^{(1)}(n)\}$ is generated by the accumulation method. Then, the corresponding differential equation of GM (1,1) model is:

$$\frac{dX^{(1)}}{dt} + aX^{(1)} = \mu \tag{5}$$

a is the developmental gray number and μ is the endogenous control gray number.

(ii) Set as the parameter vector to be estimated, and can be solved by the least square method. Solve and get:

$$\hat{\alpha} = (B^T B)^{-1} B^T Y_n \tag{6}$$

The prediction model can be obtained by solving the differential equation:

$$\hat{X}^{(1)}(k+1) = [X^{(0)}(1) - \frac{\mu}{a}]e^{-ak} + \frac{\mu}{a}, k = 0,1,2,...,n \tag{7}$$

2.5 The CRITIC Weighting Method

The basic idea of CRITIC is to use two parameters: correlation coefficient and standard deviation to determine the objective weight of the indicator. This paper refers to the methods of Žižović et al., M.et al., and uses the repeat experiment method to calculate the internal and external weights of indicators.

In the CRITIC weighting method, the objective weights between various indicators are measured by contrast strength and conflict. The standard deviation expresses the contrast strength of the indicator, which represents the size of the value difference between the evaluation schemes of the same indicator. The larger the standard deviation shows that the value difference between the schemes is greater. For example, there is a strong positive correlation between the two indicators, indicating that the conflict between the two indicators is low. In order to eliminate the influence of different dimensions on the evaluation results, it is necessary to apply a dimensionless treatment to each indicator. Which is

$$x_{ij}^{'} = \frac{x_j - x_{\min}}{x_{\max} - x_{\min}} \tag{8}$$

Calculate the index contrast strength, and here is the form of deviation

$$\begin{cases} x_j = \frac{1}{n}\sum_{i=1}^{n} x_{ij} \\ s_j = \sqrt{\frac{\sum_{i=1}^{n}(x_{ij} - \bar{x}_j)^2}{n-1}} \end{cases} \tag{9}$$

Then calculate the index correlation coefcient

$$R_j = \sum_{i=1}^{p}(1 - r_{ij}) = S_j \times R_j \tag{10}$$

Now the weight influence coefficient and finally determaine weight is

$$\begin{cases} C_j = s_j \sum_{i=1}^{p}(1 - r_{ij}) = S_j \times R_j \\ W_j = \frac{C_j}{\sum_{i=1}^{p} C_j} \end{cases} \tag{11}$$

3. Results and discussion

3.1 Calculate the growth rate

In order to broaden the scope of application of the model, this paper doesn't choose to use the collected data directly to calculate the 2016-2020 GGDP, but predict it through the gray prediction model. Therefore, the future trend of GGDP can be predicted by past GGDP.

As an indicator of the state of the economy, the calculation of growth rates is essential. Considering the comprehensiveness and convenience of the study, this paper chooses data from the United States(a developed country that has adopted GGDP), Mexico(a developing country that has adopted GGDP) and China(a developing country that has not fully implemented GGDP) for analysis.

Formula of growth rate:

$$GDP_{GR} = \frac{GDP(t) - GDP(t-1)}{GDP(t-1)} \tag{12}$$

$$GGDP_{GR} = \frac{GGDP(t) - GGDP(t-1)}{GGDP(t-1)} \tag{13}$$

GDP_{GR} is the growth rate of GDP, and $GGDP_{GR}$ is the growth rate of GGDP.

The growth rate formula is used to calculate the growth rates of GDP and GGDP for the United States(**Fig. 3**), Mexico(**Fig. 4**) and China(**Fig. 5**). And they are shown in the image below.

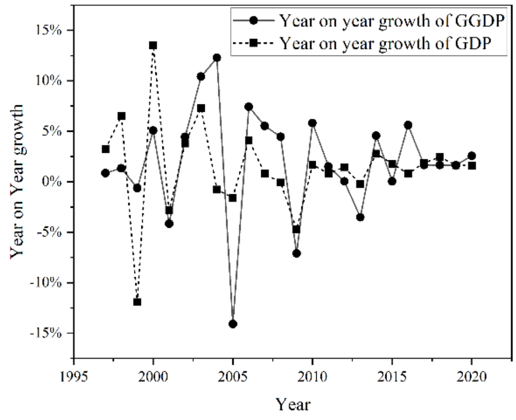

Fig. 3: Growth rate of US GDP and GGDP

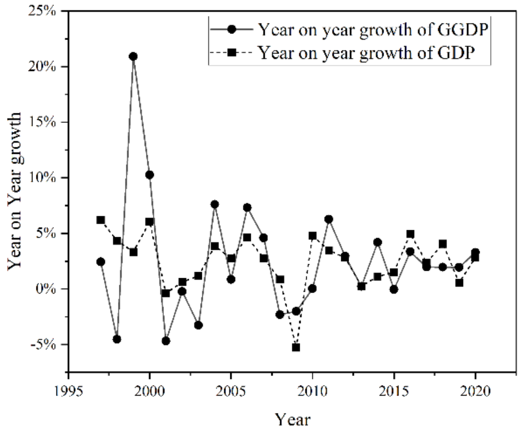

Fig. 4: Growth rate of Mexico GDP and GGDP

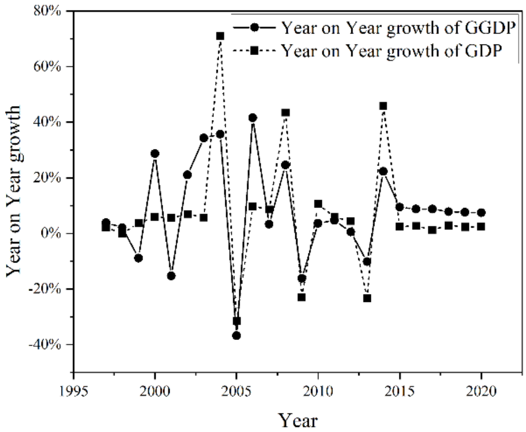

Fig. 5: Growth rate of China GDP and GGDP

As can be seen from the above figures that both GDP and GGDP of the three countries roughly fluctuate in the same direction, and in general, the growth rate of GGDP is not worse than that of GDP. From a growth rate perspective, using GGDP instead of GDP on a global scale would not cause serious damage.

3.2 Difference Contribution

Since GGDP is obtained after considering environmental factors in GDP, the larger the GGDP of a country, the more consistent its economic situation is with the concept of sustainable development. When GGDP is smaller than GDP, the smaller the difference between GDP and GGDP, the better. This paper sets an indicator to measure the environmental efforts made by different countries, named difference contribution, and the set up process is as follows:

$$DP(i)=\frac{GDP(i)-GGDP(i)}{GDP(i)}\times 100\% \tag{14}$$

$$TD=\sum_{i=1}^{3}DP(i) \tag{15}$$

$$DC(i)=\frac{DP(i)}{TD} \tag{16}$$

DP(i) is the difference percentage of the i^{th} country, TD is the total deviation of three countries and DC(i) is the difference contribution of the i^{th} country.

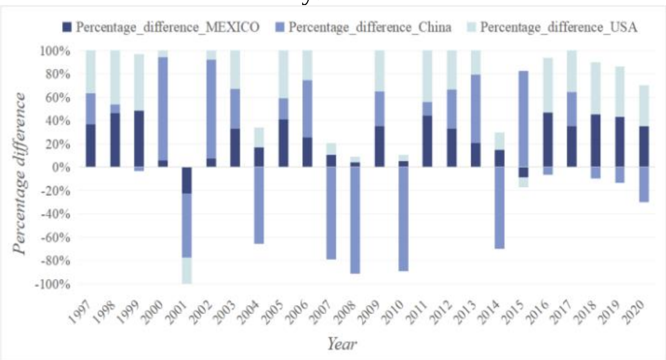

Fig. 6: Difference contribution

As shown in **Fig. 6**, the GGDPs of the three countries are less than GDPs in most years, which means that the current green economy cannot cover the consumption cost of natural resources and environmental remediation costs. In addition, the difference contribution of the United States and Mexico fluctuat slightly and remain at a relatively stable level. On the other hand, China's difference contribution fluctuates from high to low, which is not stable enough. According to the analysis of national conditions, this paper holds the opinion that the United States and Mexico notice the impact of environmental factors on the economy earlier and begin to use GGDP to measure economic health, so the difference percentage is relatively stable. However, China has not popularized GGDP nationwide at present, so the difference percentage will fluctuate greatly.

Using the same method to analyze other countries around the world, it is found that GGDP is generally smaller than GDP and has more long-term effects.

3.3 The impact of GGDP

This paper divide the discussion into developed countries and developing countries, when we study the impact of GGDP on global mitigation of climate change. Calculate the GGDP of developed and developing countries respectively, compare the differences and commonalities of GGDP between developed and developing countries through figures, and analyze the impact of GGDP on climate.

Let the United States in the developed world and China in the developing world serve as examples. Carbon dioxide levels are one of the main causes of climate change. Therefore, we preliminarily analyze the impact of GGDP on mitigating climate change by analyzing its impact on carbon dioxide emissions.

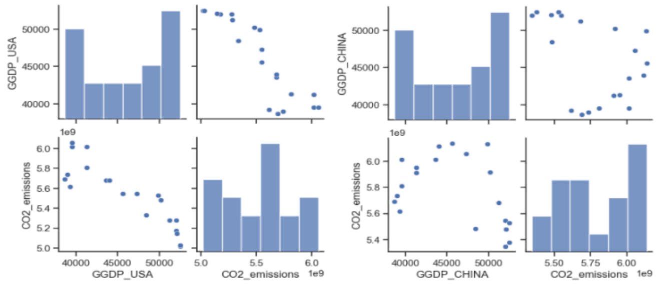

Fig. 7: Impacts of GGDP on carbon dioxide emissions in the United States and China

As shown in **Fig. 7**, carbon dioxide emissions in both the US and China initially increase with the increase of GGDP. Subsequently, carbon dioxide emissions are inversely proportional to GGDP. The larger the GGDP, the less carbon dioxide emissions. It can be known that the impact of GGDP on the environment is likely to lag behind, so this paper believes that the phenomenon of first increase and then decrease is reasonable. The model has long-term dependence, and no significant change in carbon reduction can be seen in the short term. To sum up, it can be inferred that the adoption of GGDP can mitigate global climate change， but it needs to wait for some time.

Through the above, it is known that forest cover, carbon dioxide emissions and annual mean temperature have a strong relationship with GGDP. To compare forest cover and CO^2 emissions in the United States, Mexico and China, this paper visualizes the forest cover and CO^2 emissions data for the three countries as shown in the figure below:

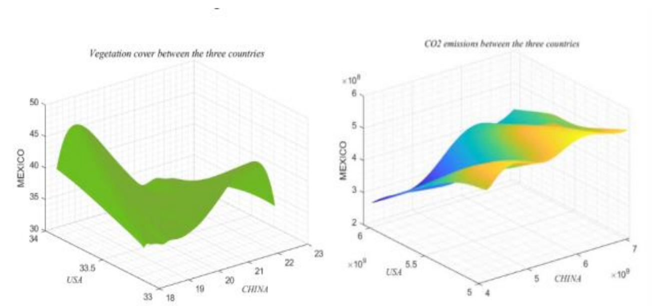

Fig. 8 Forest cover and carbon dioxide emissions in three countries

As shown in **Fig. 8**, the forest coverage of the United States and Mexico is larger than that of China, and their carbon dioxide emissions are generally smaller than that of China. Thus, this provides a basis for the phenomenon that GGDP instead of GDP is beneficial for climate change mitigation and sustainable economic development.

Besides, the potential reasons against changing the status quo is: First of all, environmental protection is a protracted battle that requires unremitting efforts from generation to generation.

Moreover, environmental protection is slow to take effect and the natural environment cannot be improved immediately. Secondly, GGDP has a lag effect on mitigating climate change. In the first three to five years of using the GGDP as a measure of the economy, there will be no significant improvement in the health of the economy or the natural environment.

3.4 Case Tracking

Results from above present the difference in percentage between the value of the traditional GDP measure and the value of the calculated Green GDP measure for the observed countries (USA, China, and MEXICO) as a deviation from the GDP. From the above results, it can be concluded that China's environmental impact is the most severe, with an average difference of 5.02%, much larger than the value of 0.87% calculated for the United States. Therefore, the choice of China as the subject of our exploration can reveal more clearly the influence of GGDP on a country. Furthermore, as China is known to be the largest developing country in the world, this object can be used as a case study for many developing countries, and it is an empirical analysis with generalization ability.

In recent years, while China's economy has achieved rapid development, it also suffers from high input and high consumption of natural resources, thereby restricting its sustainable development. Depending upon China's statistics from 2005-2020, the GGDP within the sustainable development context is calculated using the system of integrated environmental and economic accounting. The results are shown below in **Fig. 9**:

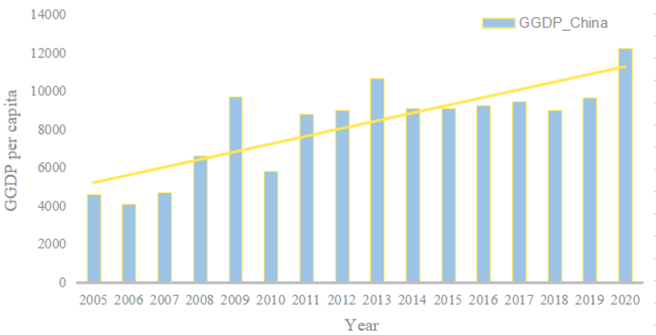

Fig. 9: Annual GDP per capita (unit $)

Taking air pollution control as an example, the weighting is first calculated using the CRITIC weighting method for the sub-indicators of the terminal branches (CO_2, SO_2 and O_3). In this case, the score for air pollution control is the minor indicators multiplied by the calculated weights and then summed.

After processing the data by the first CRITIC weighting method, the scores of the three main categories of indicators (RCED, CNRC, and AGE) can be obtained for each year. Further weighting them by the CRITIC weighting method gives the following results in **Table 3**:

Table 3: The weights of each indicator obtained by CRITIC weighting method

Indicator	Weight	Type
RCED	0.2604	Cost-based indicators
CNRC	0.2443	Cost-based indicators
AGE	0.4953	Benefit-based ndicators

And as for fulmular is mentioned below:

$$GGDP = GDP - 0.2604RCED - 0.2443CNRC + 0.4953AGE$$

As presented in **Table 3**, the weight assigned to AGE is the largest, which means that AGE is more strongly influenced by GGDP. Therefore, start with the new energy-related information, and predict the changes that will occur.

In order to compare clean energy with traditional non-renewable energy sources, a five-year gray projection is made for the period 2005-2015 for statistical data. To present the results, the following clustered bar graphs are drawn:

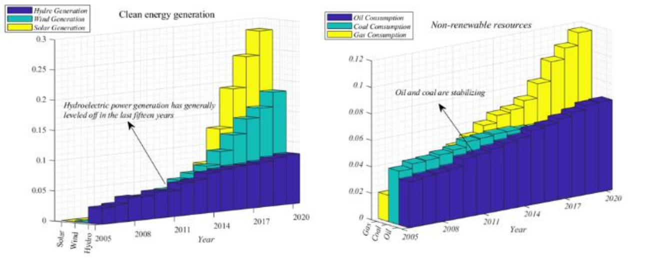

Fig. 10: Clean energy versus traditional non-renewable energy sources through the years

As shown in **Fig. 10**, the trend of new energy sources is all upward. However, the traditional non-renewable energy sources, except for natural gas, are all growing slowly and even showing a downward trend.

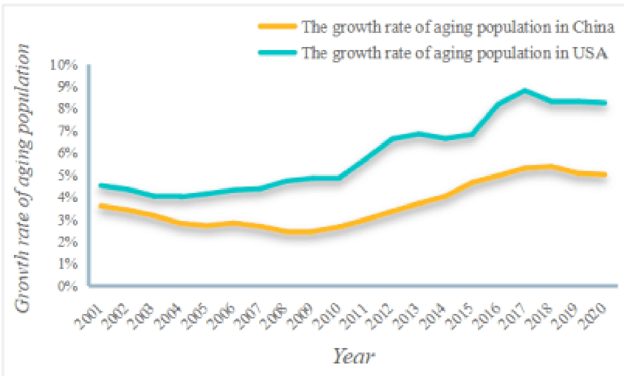

Fig. 11: The growth rate of aging population in developed and developing countries, taking China and United States (USA) as examples

As shown in **Fig. 11**, this paper turns to the phenomenon of population aging to discuss the possible impact of GGDP on China. The natural environment nurtures human beings, and when the environment becomes better, the quality of life is enhanced. This explains why the aging population in developed countries has been increasing over the years, and the annual growth rate is greater than that of developing countries. China's aging population is in the upper middle of the world, and the increasing environmental demands of its citizens make it urgent to adopt a program to develop a green economy. In general, the shift from GDP to GGDP can play a role in climate mitigation and can alleviate the dilemma that China is currently in.

4. Conclusion

This paper takes the world-accepted GGDP as the main measure of a country's economic health and study its impact on the environmental climate. The main components are as follows:

Firstly, based on environmental and economic data, this paper develops a model of the GGDP accounting system in a practical context and considers the different impacts of the system on countries with different development situations. In terms of global ecology, the adoption of the GGDP accounting system can mitigate global climate change. Economically, the benefits of the GGDP accounting system to the national economy are long-term and sustainable, but no significant benefits are seen in the short term.

Second, considering the expected global impact on climate mitigation, we explore three country-specific cases by development status and GGDP adoption. In the cases where both the United States (a developed country) and Mexico (a developing country) have adopted a green GDP accounting system, their economic health is relatively stable and the impact of environmental factors on the economy is noted earlier compared to China.

Looking ahead. The basic national conditions of China determine the Chinese modernization path. At the same time, it is also decided that the realization of the Chinese modernization path must choose green modernization, i.e., the modernization of the harmony between human beings and nature. In the future of GGDP, the country will pay more attention to clean energy, and clean energy can bring considerable income while protecting the environment. It will not only satisfy the economic benefits, but also create a greener global environment for future generations. This paper also considers the future trend of traditional non-renewable energy data, and we can see that natural gas will still be a common source of energy for people. But for better sustainability, people will gradually reduce the use of coal and the like, expecting to find another category of better and greener alternative energy.

Ethics approval

Ethics approval was not required for this research.

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Competing Interests

The authors declare no conflict of interest.
The authors have no relevant financial or non-financial interests to disclose.

Data sources

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